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1.90–1.88Ga arc magmatism of central Fennoscandia: geochemistry, U–Pb geochronology, Sm–Nd and Lu–Hf isotope systematics of plutonic–volcanic rocks from southern Finland

J. KARA¹ M. VÄISÄNEN¹ Å. JOHANSSON² Y. LAHAYE³ H. O'BRIEN³ O. EKLUND⁴

¹Department of Geography and Geology, University of Turku
FI-20014 Turku, Finland. Kara E-mail: jkmar@utu.fi

²Department of Geosciences, Swedish Museum of Natural History
P.O. Box 50007, SE-104 05 Stockholm, Sweden

³Geological Survey of Finland
P.O. Box 96, FI-02151 Espoo, Finland

⁴Geology and Mineralogy, Åbo Akademi University
FI-20500 Turku, Finland

ABSTRACT

The earliest Svecofennian magmatism in southern Finland has been dated to 1.90–1.88Ga. As an example of this, the Orijärvi (*ca.* 1.89Ga) and Enklinge (*ca.* 1.88Ga) volcanic centres comprise bimodal plutonic batholiths surrounded by volcanic rocks of comparable ages and chemical compositions. The rock types range from gabbros to granites and indicate a subduction-related continental margin setting. The zircons from the Orijärvi granodiorite define an age of 1892±4Ma whereas the Enklinge granodiorite yields an age of 1882±6Ma. Several inherited ages of 2.25–1.95Ga as well as younger metamorphic ages of 1.86–1.80Ga were found in the Enklinge granodiorite. The initial ϵ_{Nd} values of the mafic rocks from both locations fall in the range +1.1 to +2.9, whereas the felsic rocks exhibit initial ϵ_{Nd} values of -0.4 to +1.2. The magmatic zircons from the Orijärvi and Enklinge granodiorites show average initial ϵ_{Hf} values of -1.1 (at 1892Ma) and zero (at 1882Ma), respectively, both with a spread of about 7 ϵ -units. The initial ϵ_{Hf} values for the inherited zircons from Enklinge range from +3.5 to +7.6 with increasing age. The Sm–Nd data indicate that the mafic rocks were derived from a “mildly depleted” mantle source while the felsic rocks show some crustal contribution. Also, the variation in ϵ_{Hf} values indicates minor mixing between mildly depleted mantle-derived magmas and crustal sources. U–Pb ages and Hf isotopes for inherited zircons from the Enklinge granodiorite suggest the presence of juvenile Svecofennian “proto-crust” at depth.

KEYWORDS | Fennoscandian shield. Svecofennian orogeny. Lu–Hf. U–Pb. Sm–Nd. Geochemistry.

INTRODUCTION

Major crust-forming processes occurred in connection with the amalgamation of the supercontinent Columbia *a.k.a.* Nuna during Paleoproterozoic time (*e.g.* Rogers and Santosh, 2002). One of its components, the Svecofennian

Orogen (SO) in the Fennoscandian shield (Fig. 1A), was mainly formed between *ca.* 1.96 and 1.77Ga through accretionary (Gorbatshev and Bogdanova, 1993; Hermansson *et al.*, 2008; Stephens and Andersson, 2015) or combined accretionary and collisional (Lahtinen, 1994; Lahtinen *et al.*, 2005) processes. The orogen also forms

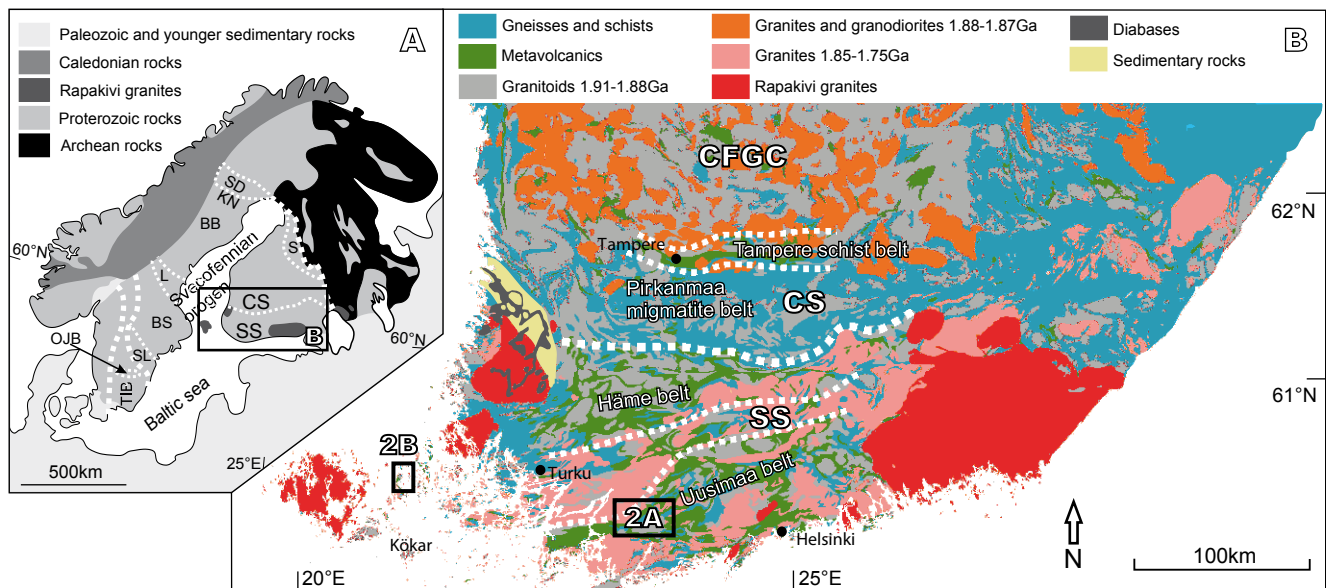


FIGURE 1. A) Geological overview of the Fennoscandian shield and proposed terrane distribution, modified after Koistinen *et al.* (2001). The thick white dashed lines represent the borders of the Svecofennian orogen and Transscandinavian igneous belt, whereas the narrow-dashed lines represent proposed terrane boundaries within the Svecofennian orogen. CS=Central Svecofennia, SS=Southern Svecofennia, S=Savo arc, SD=Skellefte District, KN=Knaften arc, BB=Bothian Basin, L=Ljusdal lithotectonic unit, BS=Bergslagen lithotectonic unit, SL=Småland Lithotectonic unit, TIB=Transscandinavian Igneous Belt, OJB=Oskarshamn-Jönköping Belt. Area of map B) is indicated by a black rectangle. B) General geological map of southern Finland, modified after Kallioperä-Bedrock of Finland 1:200,000. CFGC=Central Finland Granitoid Complex. The white thicker dashed line represents proposed border between Central and Southern Svecofennia (CS and SS, respectively), whereas the white narrower lines represent proposed borders of the other major lithotectonic units. Study areas indicated by black rectangles (2A=Orijärvi, 2B=Enklinge).

a part of the Great Proterozoic Accretionary Orogens, which in places have experienced the longest duration of subduction in the Earth's history, up to 900Ma (Condie, 2013). The SO covers large areas in Finland and Sweden, and smaller areas in Norway and Russia. Much of it is covered by Paleozoic sediments in the South and southeast (Fig. 1A).

The oldest recognised magmatism in the SO is related to subduction which formed almost juvenile volcanic arcs in a continental margin setting (1.96-1.88Ga; *e.g.* Kähkönen, 2005; Stephens *et al.*, 2009 and references therein). The volcanic arcs in the SO are mainly composed of extrusive igneous rocks, but magma chambers or subvolcanic intrusions are also present. Such magma chambers have long been recognised in Sweden (Stephens *et al.*, 2009 and references therein) but only occasionally considered in Finland (Colley and Westra, 1987; Ehlers and Lindroos, 1990; Väisänen and Mänttari, 2002; Talikka and Mänttari, 2005). It has been recognised that some parts of the SO have initial ϵ_{Nd} values close to zero and depleted mantle model ages older than 2.1Ga, indicating an older contribution to the source region (*e.g.* Huhma, 1986; Patchett *et al.*, 1987; Andersson, 1997; Lahtinen and Huhma, 1997). Single zircon U-Pb dating has also revealed inherited older zircons in the oldest plutonic rocks (*e.g.* Ehlers *et al.*, 2004). These findings have evoked models where *ca.* 2.2-2.0Ga small continental fragments, microcratons or pieces of Svecofennian "proto-crust"

are hidden under the present crust (Lahtinen *et al.*, 2005; Andersson *et al.*, 2011). However, no direct observations of these microcratons have been made.

In this study, we present whole rock geochemical, U-Pb, Sm-Nd, and Lu-Hf isotope data from two 1.90-1.88Ga magmatic centres in southern Finland: the Orijärvi and Enklinge areas. They comprise plutonic centres surrounded by extrusive volcanic rocks of corresponding ages and chemical compositions. The focus here is on the plutonic and dyke rocks since they have not been previously studied as extensively as their extrusive counterparts. Our aim is to study the magma source/s and the nature of the oldest magmatic rocks of central Fennoscandia. In addition, we evaluate the existence of the proposed proto-crust below the central Fennoscandian bedrock in the light of new Lu-Hf isotope data.

REGIONAL GEOLOGICAL SETTING

The Svecofennian orogen in Finland and Sweden is composed of several large units defined as terranes or lithotectonic units. The oldest volcanic arc-type igneous rocks are found in northern Sweden (1.96-1.92Ga Knaften arc; Wasström, 1993, 2005) and the youngest in southern Sweden (1.83-1.82Ga Oskarshamn-Jönköping Belt; Mansfeld *et al.*, 2005). In the central part, three main terranes are recognised in Finland: the Savo arc (S),

Central Svecofennia (CS) and Southern Svecofennia (SS, Fig. 1A) (Korsman *et al.*, 1997; Kähkönen, 2005).

The Savo arc exposes the oldest Svecofennian igneous rocks in Finland (*ca.* 1.92 Ga; Lahtinen, 1994; Vaasjoki *et al.*, 2003) and it is considered an equivalent to the Knaften arc (KN) in Sweden with roughly similar ages (Wasström, 1993; Eliasson *et al.*, 2001; Guitreau *et al.*, 2014). The ages of the volcanic arc-related igneous rocks in central and southern Svecofennia fall between 1.90 and 1.88 Ga (*e.g.* Kähkönen, 2005). A few slightly older (1.91 Ga; Johansson and Stephens, 2017) and younger (1.85 Ga; *e.g.* Stephens and Andersson, 2015) rocks also occur. It is traditionally considered that southern Svecofennia and the Bergslagen area (BS) in South-central Sweden belong to the same unit (*e.g.* Valbracht *et al.*, 1994; Nironen, 1997; Lahtinen *et al.*, 2005), although the presence of large intervening shear zones such as the Singö shear zone along the coast in East-central Sweden and the South Finland shear zone makes such correlations somewhat problematic (*cf.* Torvela and Ehlers, 2010; Bogdanova *et al.*, 2015).

Southern Svecofennia

Southern Svecofennia comprises two parallel volcanic-sedimentary belts: the Häme and Uusimaa belts (Fig. 1B; Kähkönen, 2005 and references therein). The zircon ages in volcanic rocks in both belts are *ca.* 1.90–1.88 Ga (*e.g.* Väisänen and Mänttari, 2002; Ehlers *et al.*, 2004; Skyttä *et al.*, 2005; Väisänen and Kirkland, 2008; Saalman *et al.*, 2009). Both belts show arc-type geochemical affinities, and the Häme belt is apparently less mature than the bulk of the Uusimaa belt (Lahtinen, 1996; Kähkönen, 2005).

The relationship between the two volcanic belts is ambiguous (*cf.* Kähkönen, 2005). Korja *et al.* (2006) regarded the Häme and Uusimaa belts as separate terranes, whereas Väisänen and Mänttari (2002) suggested that the belts belonged to the same arc system but were rifted apart. The rift basin was filled with felsic volcanic rocks, tholeiitic mafic/ultramafic lavas with E-MORB affinity (*ca.* 1.88–1.87 Ga), sedimentary carbonates (now marbles) and detrital sediments (now mica gneisses; *e.g.* Nironen *et al.*, 2016 and references therein).

The Häme belt includes several mafic/ultramafic plutonic rocks, which often show layered structures. The largest of these is the Hyvinkää layered intrusion, which Peltonen (2005) regarded as synplutonic to the volcanic rocks of the area (see also Eerola, 2002). The interpretation is supported by the U–Pb zircon ages of the gabbro (1880 ± 5 Ma, Patchett and Kouvo, 1986) and the plagioclase-phyric mafic volcanic rock (1880 ± 3 Ma,

Suominen, 1988). Such synvolcanic plutonism is described for central Svecofennia as well (*e.g.* Talikka and Mänttari, 2005), and it is widespread in the Bergslagen area in Sweden (Lundström *et al.*, 1998; Andersson *et al.*, 2006b; Hermansson *et al.*, 2008; Stephens *et al.*, 2009).

The volcanic rocks in the Uusimaa belt show continental margin and rifting type lithological associations and geochemical affinities (Kähkönen, 2005; Weihed *et al.*, 2005). The belt has indications of an older, *ca.* 2.1–1.91 Ga contribution to the magmatism as indicated by initial ϵ_{Nd} values around zero (Huhma, 1986; Patchett and Kouvo, 1986; Lahtinen and Huhma, 1997; this study) as well as detrital zircons of that age in metasediments and inherited zircons in igneous rocks (*e.g.* Claesson *et al.*, 1993; Lahtinen *et al.*, 2002; Ehlers *et al.*, 2004; Bergman *et al.*, 2008; Lahtinen and Nironen, 2010).

Enklinge and Orijärvi are both well-preserved non-migmatitic mega-enclaves surrounded by higher-grade and more deformed areas. Therefore, Enklinge and Orijärvi make excellent targets to study the earliest events in southern Svecofennia (Ehlers and Lindroos, 1990; Ploegsma and Westra, 1990; Skyttä *et al.*, 2006). The Orijärvi area is situated in the middle of the Uusimaa belt and is a type example of it (*e.g.* Kähkönen, 2005). The Enklinge area, however, is situated in the archipelago to the West of the continuous Häme and Uusimaa belts, and it remains unclear whether it is part of any of them.

Study areas

Orijärvi area

The bedrock in the Orijärvi area (Fig. 2A) in the middle of the Uusimaa belt mainly consists of apparently bimodal volcanic rocks with sedimentary intercalations (Eskola, 1914; Väisänen and Mänttari, 2002; Kähkönen, 2005; Skyttä *et al.*, 2005). The volcanic rocks are divided into four formations (fms.): the lowermost Orijärvi Formation (Fm.) is a volcanic arc-type bimodal unit with marble and iron formation intercalations as well as Cu–Zn–Pb mineralizations (Eskola, 1914; Latvalahti, 1979; Väisänen and Mänttari, 2002). The overlying Kisko Fm. is geochemically more evolved, and volcanic rocks range from basalts to rhyolites. The arc rifting started with the Toija Fm. which once again comprises bimodal volcanic rocks. The rifting continued with the Salittu Fm., which mainly consists of E-MORB type basalts and picrites. Age results of the volcanic rocks fall between 1895 ± 3 Ma (Orijärvi Fm.) and 1878 ± 4 Ma (for both the Kisko and Toija fms.; Väisänen and Mänttari, 2002; Väisänen and Kirkland, 2008), with the uppermost Salittu Fm. being undated.

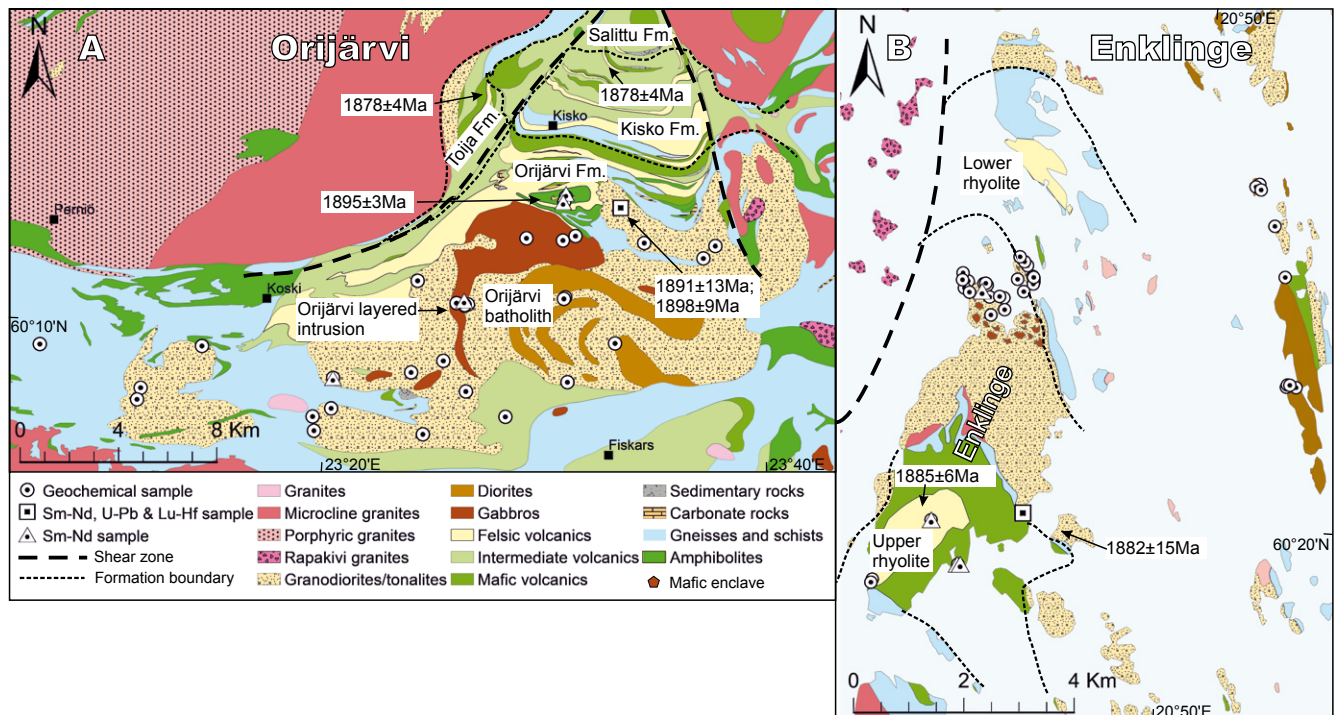


FIGURE 2. Detailed geological map of the A) Orijärvi and B) Enklinge study areas with age determinations, isotope and geochemical sampling sites indicated. Figures are modified after Kallioperä-Bedrock of Finland 1:200,000 (both), Skyttä *et al.* (2006) (Orijärvi) and Ehlers and Lindroos (1990) (Enklinge). For U-Pb ages, see text for references.

The Orijärvi batholith is a composite pluton, where mafic and felsic rocks apparently alternate. Magma mingling between felsic and mafic components is also common (Fig. 3A; B). Mafic rocks are more common in the core, and felsic rocks dominate at the fringes of the pluton. However, a complex structural evolution (Ploegsma and Westra, 1990; Skyttä *et al.*, 2006) might have disrupted the original order of rock types within the pluton. The mafic plutonic rocks show locally a layered structure (Sarapää *et al.*, 2005).

The U-Pb zircon age of the Orijärvi granodiorite (outer border of the batholith) has been determined to 1891 ± 13 Ma (Huhma, 1986) and 1898 ± 9 Ma (Väisänen *et al.*, 2002; *cf.* this study). Within errors, this is the same as the age of the felsic volcanic rock from the lowest stratigraphic level, and the Orijärvi batholith is regarded as a magma chamber that fed the surrounding volcanic rocks (Colley and Westra, 1987; Väisänen and Mänttari, 2002).

Enklinge area

The well-preserved Enklinge volcanic-plutonic centre in the Åland archipelago in SW Finland consists of subaqueous felsic and mafic volcanic rocks with sedimentary intercalations (Fig. 2B; Sederholm, 1934; Rancken, 1953; Ehlers, 1976). The bedrock was divided into upper and lower strata (Ehlers and Lindroos, 1990).

The lower strata consist of felsic schists, graywackes and the lower rhyolitic series which are capped by thin marble layers. The upper strata are composed of mafic and intermediate volcanics, including pillow lavas and lava flows. The upper series of rhyolites is on top of the stratigraphy.

The lower volcanic rocks are intruded and surrounded by syntectonic granodiorite-tonalite and related dacitic quartz porphyric dykes (Ehlers and Lindroos, 1990). Both granodiorite and dacitic dykes contain mafic enclaves, up to 50% of the volume of the bedrock in the northern side of Enklinge (Fig. 3C; D; Impola, 2004). Most of the dykes are bordered by basalts indicating coeval bimodal magmatism. Chemically, the dykes and the surrounding granodiorite are identical but they both differ slightly from the extrusive rhyolites (Ehlers and Lindroos, 1990).

The upper rhyolite and syntectonic granodiorite have been dated to 1885 ± 6 Ma and 1882 ± 15 Ma, respectively (Suominen, 1987; Ehlers *et al.*, 2004;). Ehlers *et al.* (2004) also determined ages for three similar gneissic granodiorites a few kilometres North of Enklinge, from Sottunga (30 km South from Enklinge) and from Kökar (50 km SE from Enklinge), and obtained identical ages of 1884 ± 5 Ma for all of them. This supports the coeval nature of the Enklinge rhyolite and surrounding granodiorite, although they are different in geochemistry.

ANALYTICAL METHODS

A total of 75 whole rock samples were studied, of which 34 were from Orijärvi and 41 from Enklinge. The data include plutonic, dyke and volcanic rock samples. Analyses were done by Inductively Coupled Plasma-Optical Emission Spectrometry (ICP-OES) and by Inductively Coupled Plasma-Mass Spectrometry (ICP-MS) at three different laboratories.

Two granodiorite samples, one from each study area, were selected for U-Pb spot analyses on zircon in order to determine their crystallization ages, and to perform Lu-Hf analyses on the same zircon grains. The Orijärvi granodiorite U-Pb dating analyses were performed using a Nu Plasma AttoM single collector ICP-MS, whereas the Enklinge granodiorite zircon U-Pb dating analyses were performed using a Nu Plasma HR multicollector ICP-MS, both at the Geological Survey of Finland in Espoo. With the latter instrument, in-situ zircon Lu-Hf isotope analyses were performed on the same or adjacent domains of the grains on which the U-Pb dating was done.

The Sm-Nd analyses were performed on nine samples, of which four were from Orijärvi and five from Enklinge, by a Finnigan MAT261 multicollector mass spectrometer at the Department of Geosciences, Swedish Museum of Natural History.

The full description of the analytical methods used in this study and the whole rock geochemical data (Table I), U-Pb isotopic data (Table II), Sm-Nd isotopic data (Table III) and Lu-Hf isotopic data (Table IV) are provided in the ELECTRONIC APPENDIX.

RESULTS

Whole rock geochemistry

Major elements

The compositions of the Orijärvi and Enklinge samples range from gabbroic to granitic in the Total Alkali *vs.* Silica (TAS) diagram (Fig. 4A). The classification of the samples (mafic-felsic) was done merely based on silica content of the rocks using 65wt.% of SiO₂ as a threshold value. The plutonic-dyke-volcanic-cumulate division was defined according to field observations. On the K₂O *vs.* SiO₂ diagram (Fig. 5) the mafic rocks from Orijärvi are calc-alkaline but those from Enklinge fall both in the calc-alkaline and tholeiitic fields. One high-K and one shoshonitic outlier can also be found within the Enklinge mafic rocks. The majority of the rocks follow a similar chemical evolution in the major elements in both study

areas and the only slight difference can be found in the P₂O₅ contents; most of the Orijärvi mafic rocks are enriched in P₂O₅ compared to the Enklinge ones (Fig. 5). The felsic rocks follow similar trends as the mafic rocks in most of the major element diagrams; only Na₂O content shows a drop towards lower values between mafic and felsic rocks, and K₂O content shows a large spread between 0.24 and 7.7wt.%.

Two subgroups can be distinguished as separate from this ‘main trend’ based on major element compositions: Orijärvi (six samples) and Enklinge (five samples). The five accumulations of Enklinge are characterized by ferro-magnesian minerals and resulting high MgO and Mg# values, slightly elevated Fe₂O₃ and correspondingly low Na₂O, Al₂O₃ and P₂O₅ contents (Fig. 5). Orijärvi contains five samples of layered intrusions and one separate gabbro (65-MAV-02). The rocks from the Orijärvi layered intrusion are poor in silica (SiO₂ 39-54wt.%). Four of the samples, taken from the gabbroic and the hornblende-rich parts, are enriched in TiO₂ and Fe₂O₃ but rather depleted in MgO. One of these samples (45-MAV-02; gabbro) shows anomalously high P₂O₅ content. The sample taken from the plagioclase part (TKJ-13-10-4; anorthosite) shows high Al₂O₃ and Na₂O contents but is depleted in MgO and Fe₂O₃. The

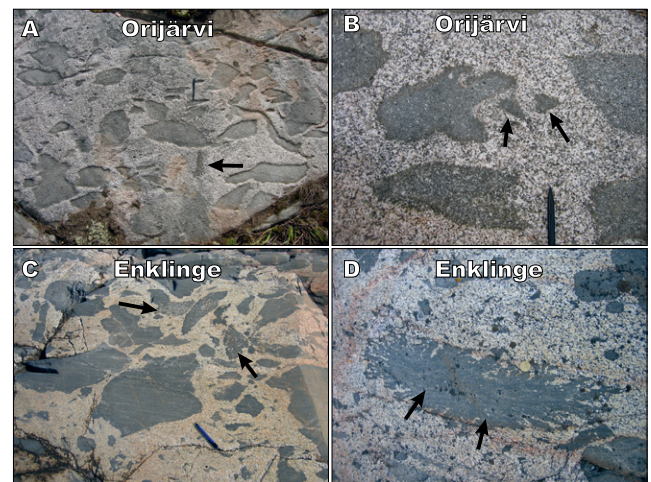


FIGURE 3. Field photos from the study areas. A) Magma mingling and mixing from the Orijärvi batholith. A few mafic enclaves, one of them indicated by a black arrow, show incipient magma mixing between mafic and felsic endmembers resulting in intermediate composition and a blurred boundary between the enclave and the felsic magma. B) Detailed photo from a mafic enclave from Orijärvi. The felsic magma has scavenged two small mafic fragments (black arrows) from the parent enclave on the left. On the left side of the pen there is an enclave with an intermediate composition similar to the one in Fig. 3A. C) Mafic and felsic magma mingling and mixing in the northern part of Enklinge. Black arrows indicate two enclaves with incipient magma mixing. D) The classical mafic enclave from Enklinge, first described by Sederholm (1934) and also found on the front cover of *Lithos* Vol. 116 (Eklund *et al.*, 2010). The outline of the enclave is resorbed by the surrounding felsic magma and a few feldspar phenocrysts are enclosed in the enclave (black arrows), suggesting coeval mafic and felsic magmas.

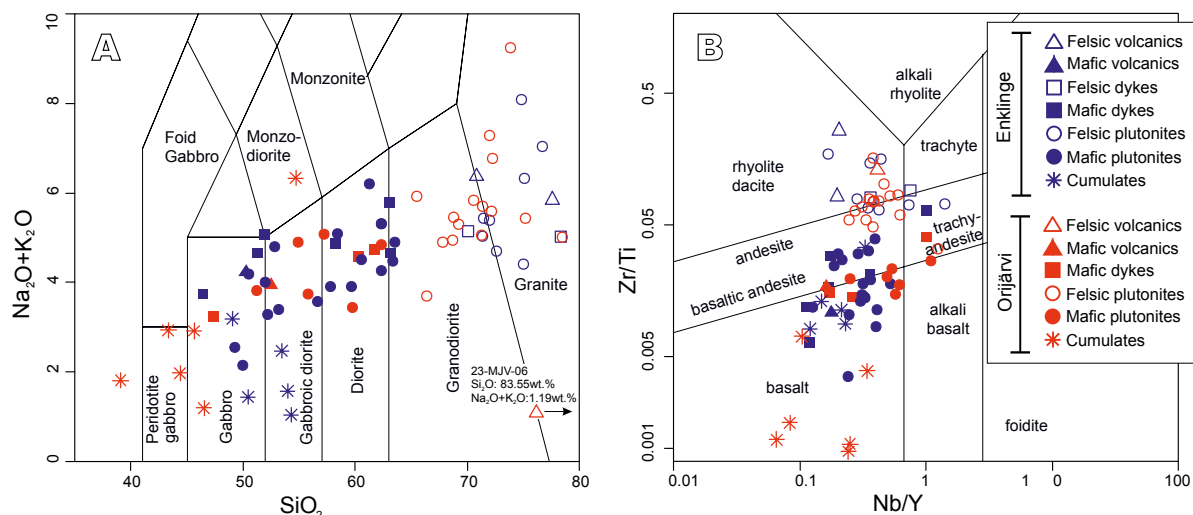


FIGURE 4. A) Total Alkalis vs. Silica (TAS) classification diagram (Middlemost, 1985) of the studied rocks. B) Log Zr/Ti vs. log Nb/Y classification diagram (Winchester and Floyd, 1977, modified by Pearce, 1996).

contents, high Mg# value and very low Na_2O , TiO_2 and P_2O_5 contents compared to the other mafic rocks from Orijarvi (Fig. 5). One rhyolite sample from Orijarvi (23-MJV-06) is hydrothermally altered, which can be seen in high silica (85wt.% SiO_2), very low alkalis (0.8wt.% Na_2O and 0.4wt.% K_2O) and low mobile trace element concentrations (below), so it was excluded from the major element examination but included in the trace element diagrams. The mafic rocks from both study areas are metaluminous except one peraluminous sample from Enklinge. The felsic rocks are metaluminous to peraluminous with Alumina Saturation Index (ASI, molar A/CNK : $(\text{Al}_2\text{O}_3/\text{CaO}+\text{Na}_2\text{O}+\text{K}_2\text{O})$) between 0.95 and 1.18 (Fig. 5).

Trace elements

The log Zr/Ti vs. log Nb/Y classification diagram (Winchester and Floyd, 1977, modified by Pearce, 1996) was used to study the degree of alteration of the samples (Fig. 4B). All the samples form a rather tight and continuous trend from basalts to rhyolites, as in the TAS diagram (Fig. 4A), which supports their unaltered nature. The altered rhyolite sample from Orijarvi plots in the same group as its plutonic counterparts.

The Orijarvi mafic rocks tend to show higher Ba, Sr and Th concentrations compared to those from Enklinge (Fig. 6). Although the trace element data from the mafic rocks from both localities are a little scattered, the majority exhibit similar trace element characteristics in the multi-element diagram showing elevated (relative enrichment) Rb, Ba, Th, U, K and Pb concentrations and distinct negative anomalies (relative depletion) of Nb, Ta and P (Fig. 7). This trend is shared with mafic dykes and

volcanics. All the mafic rocks are enriched in LREEs and depleted in HREEs but the rocks from Orijarvi generally show higher LREE concentrations, whereas the Enklinge mafics exhibit flatter REE spectra with higher HREE (Fig. 7). The samples PENK-25 (gabbro), PENK-46 (gabbro), 6-JPI-00 (gabbro dyke) and 12-JPI-00 (gabbro) from Enklinge show a flat, almost MORB-like REE pattern with a relative HREE enrichment. The gabbro sample 31-MJV-06 from Orijarvi differs from the other mafic rocks by its anomalously low HREE concentration. The majority of the mafic samples have AN Eu/Eu* ratio under 1.3.

The trace element data on all the felsic rocks from both localities show large variation in certain Large Ion Lithophile Elements (LILEs) such as Rb, Ba, Sr, Th and Zr. The Orijarvi felsic rocks exhibit lower Cr concentrations than those from Enklinge (Fig. 6). In the multi-element diagram, the felsic plutonic rocks from both localities show very similar trace element patterns with Rb, Ba, Th, U, K and Pb enrichment and depletion of High Field Strength Elements (HFSE) such as Nb and Ta (Fig. 7). The felsic plutonic rocks from both localities are enriched in LREEs and relatively depleted in HREEs. The rocks show mostly negative Eu anomalies and Eu/Eu* ratios under 1.15, except one tonalite sample from Enklinge (21-JPI-00) and two granodiorite samples from Orijarvi (37.2-MAV-02 and 50-MAV-02) which exhibit more positive Eu peaks. The two felsic dykes from Enklinge show very similar characteristics as the felsic plutonics. The two felsic volcanic rocks from Enklinge exhibit slightly different trace element compositions compared to the other felsic rocks from Enklinge with higher HFSE and REE concentrations but low Cr and Pb concentration (Figs. 6 and 7). The rhyolite sample

from Orijärvi (23-MJV-06) shows a similar composition in HFSEs compared to the other felsic rocks but it is depleted in LILEs due to hydrothermal alteration.

The mafic cumulates from Enklinge also stand out in the trace element data. They show very low LILE values as

well as low Th, Sr, Zr and Nb concentrations but very high Cr and Ni concentrations. In the multi-element diagram, the cumulate group has similar pattern as the other mafic rocks but their REE pattern is fairly flat (Fig. 7). The Enklinge cumulates also show small Eu anomalies, with Eu/Eu* ratios varying from 0.8 to 1.52.

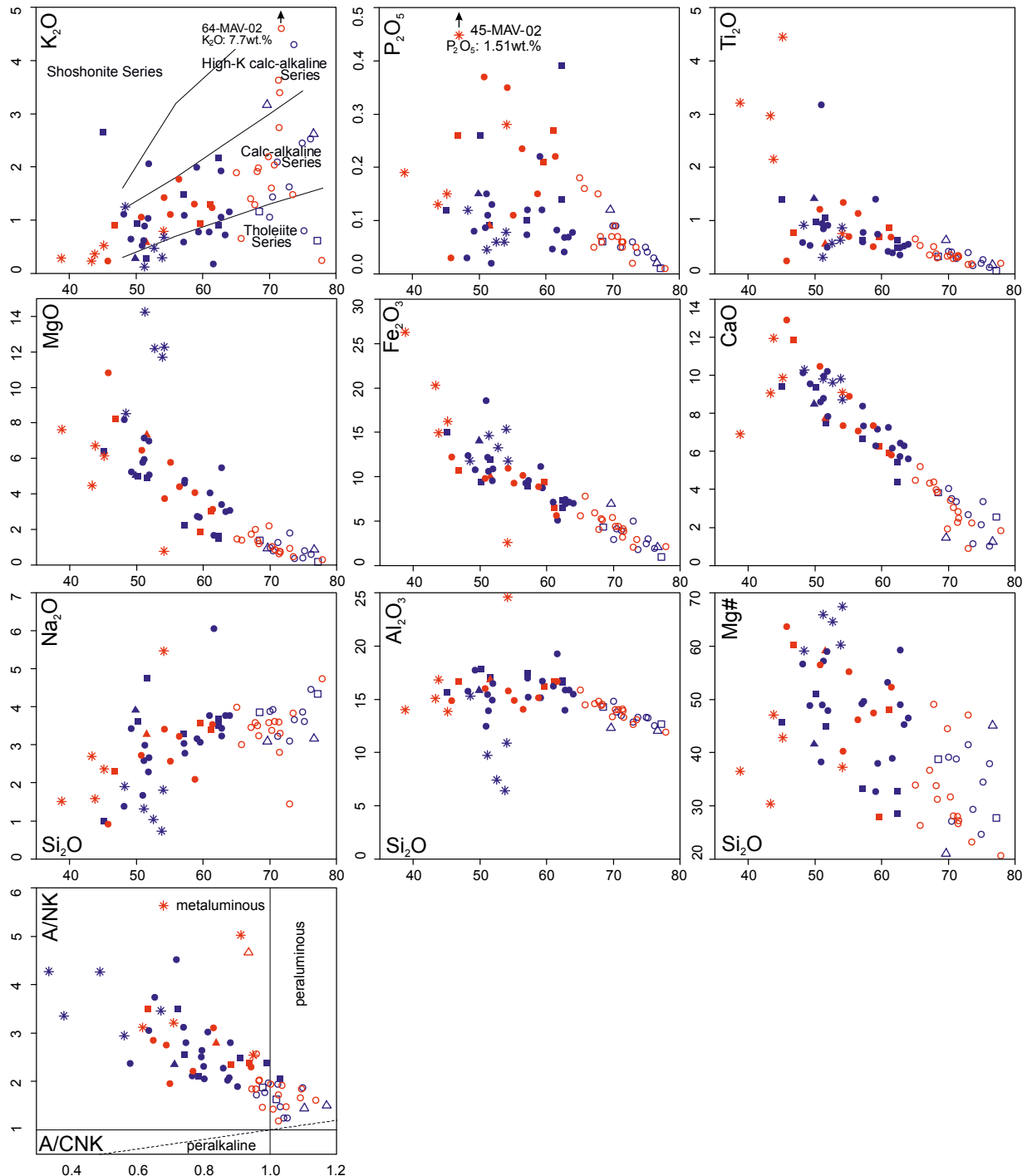


FIGURE 5. Selected major element vs. silica diagrams. K_2O vs. SiO_2 classification after Peccerillo and Taylor (1976). $Mg\#$ ($100 \times MgO / (FeO + MgO)$), A/NK ($Al_2O_3 / (Na_2O + K_2O)$) and A/CNK ($Al_2O_3 / (CaO + Na_2O + K_2O)$) calculated with GCDkit-software (Janousek *et al.*, 2006). All values in weight% except $Mg\#$ and values in the A/CNK diagram. Symbols as in Figure 4.

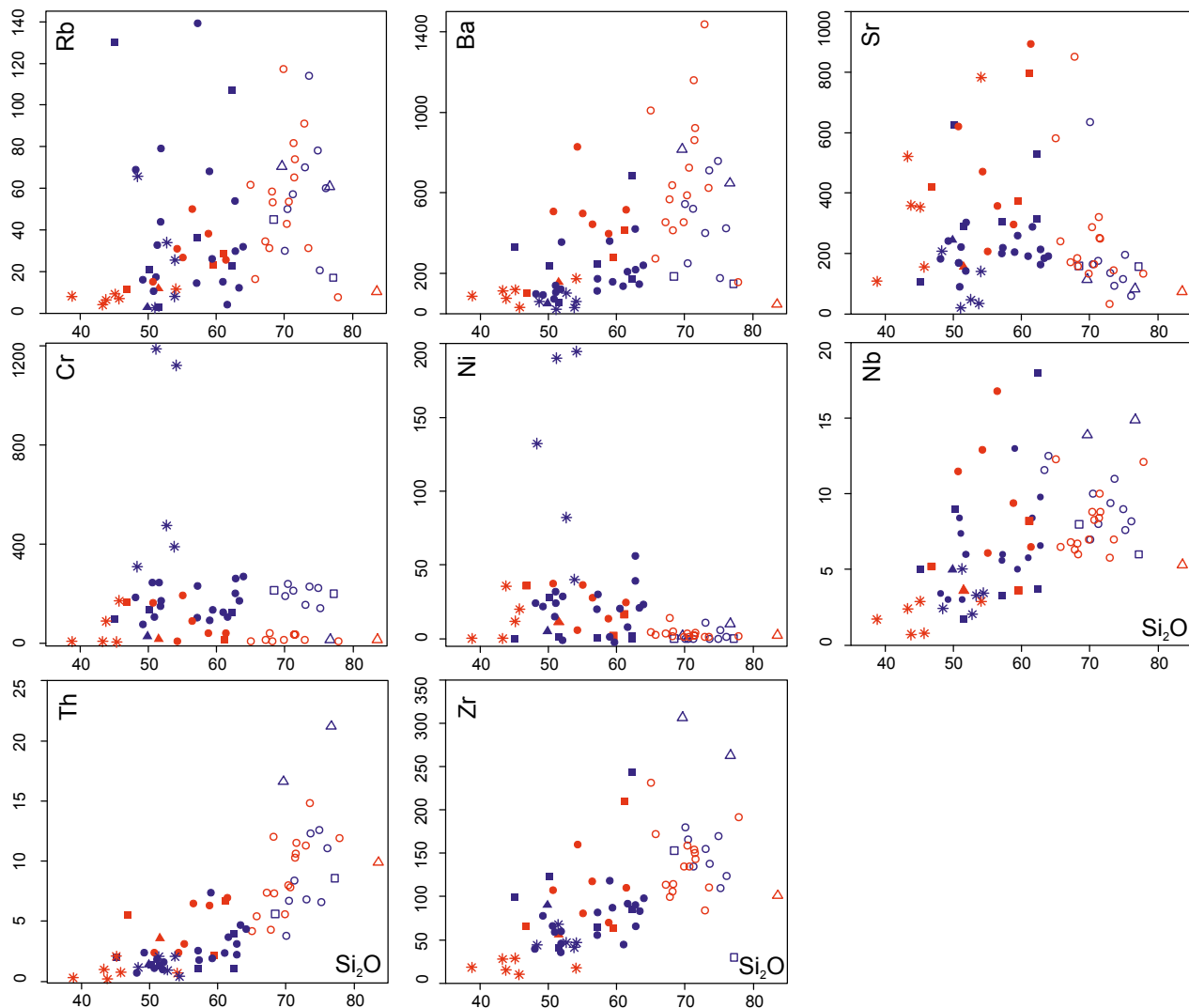


FIGURE 6. Selected trace element diagrams. All values in ppm. Symbols as in Figure 4.

The Orijärvi layered intrusion rocks show very low Rb, Ba, Zr and Nb concentrations, relatively low Ni and Cr concentrations but rather high Sr and P concentration, and in part very high Pb, compared to the other mafic rocks from both localities (Figs. 6 and 7). The REE concentrations are generally low but the rocks are relatively enriched in the LREEs, depleted in the HREEs, with Eu showing a positive peak in the REE diagram (Fig. 7). Eu/Eu* ratios are higher than in other samples, showing values between 1.36 and 3.51. The sample 65-MAV-02 from Orijärvi exhibits similar trace element characteristics as the Orijärvi layered intrusion rocks except it shows negative Eu anomaly.

U-Pb zircon analyses

The zircons from the Orijärvi granodiorite (29a-MJV-06) range from euhedral to more rounded, subhedral grains

(Fig. 8A; B) and their colour varies from transparent to light brown. The grains are mainly elongated, 50-150µm in length and 20-100µm in width. The inner structure of the grains is mostly very homogeneous and few crystals show any distinct oscillatory zoning. Cracks and metamict rims are common. The BSE-images show a few cores (Fig. 8B) but they were too small to be analysed with a 25µm spot size so that possible xenocrystic cores were not verified. A total of 12 analyses were performed on 12 grains. Nine of them yielded a concordia age of 1892 ± 4 Ma (2σ ; MSWD=0.42) and 10 analyses showed an almost identical weighted average $^{207}\text{Pb}/^{206}\text{Pb}$ age of 1892 ± 5 Ma (2σ ; MSWD=0.81; Fig. 9A).

The Enklings granodiorite (3-MJV-06) shows a wide range of zircon shapes but two main types are distinguished based on the degree of metamictization: a group of “euhedral” grains and a group of very heterogeneous

grains. The euhedral grains are also quite metamictic and have cracks, inclusions and inherited cores/domains (Fig. 8C; D). They are only slightly elongated, about 100–200 μm in length. The euhedral zircons show oscillatory zoning and metamictization have advanced following the growing pattern of the grain. The “heterogeneous” group includes large, rounded, about 100–300 μm -long grains with a wide variety of shapes, which are full of inclusions and almost completely metamictic. All the 42 U–Pb analyses were performed on the euhedral group of zircons. Several different age populations were found (Fig. 9B; C) out of which a group with a concordia

age of $1882 \pm 6 \text{ Ma}$ (2σ ; MSWD=4.2; $n=9/15$) and a $^{207}\text{Pb}/^{206}\text{Pb}$ age of 1880 ± 4 (2σ ; MSWD=0.89; $n=15/15$) are regarded to represent the age of magma crystallisation (Fig. 9C; D). The older zircons probably represent several different inherited populations. The six oldest analyses show $^{207}\text{Pb}/^{206}\text{Pb}$ ages between 2247 Ma and 2049 Ma. Two younger inherited populations yielded $^{207}\text{Pb}/^{206}\text{Pb}$ ages of $1952 \pm 16 \text{ Ma}$ (2σ ; MSWD=0.0063; $n=3$; Fig. 9C) and $1988 \pm 13 \text{ Ma}$ (2σ ; MSWD=0.32; $n=4$; Fig. 9C). The youngest 14 zircons (younger than crystallisation) show a continuous $^{207}\text{Pb}/^{206}\text{Pb}$ age trend between 1859 and 1802 Ma. Nine analyses yielded a concordia age of $1849 \pm 9 \text{ Ma}$

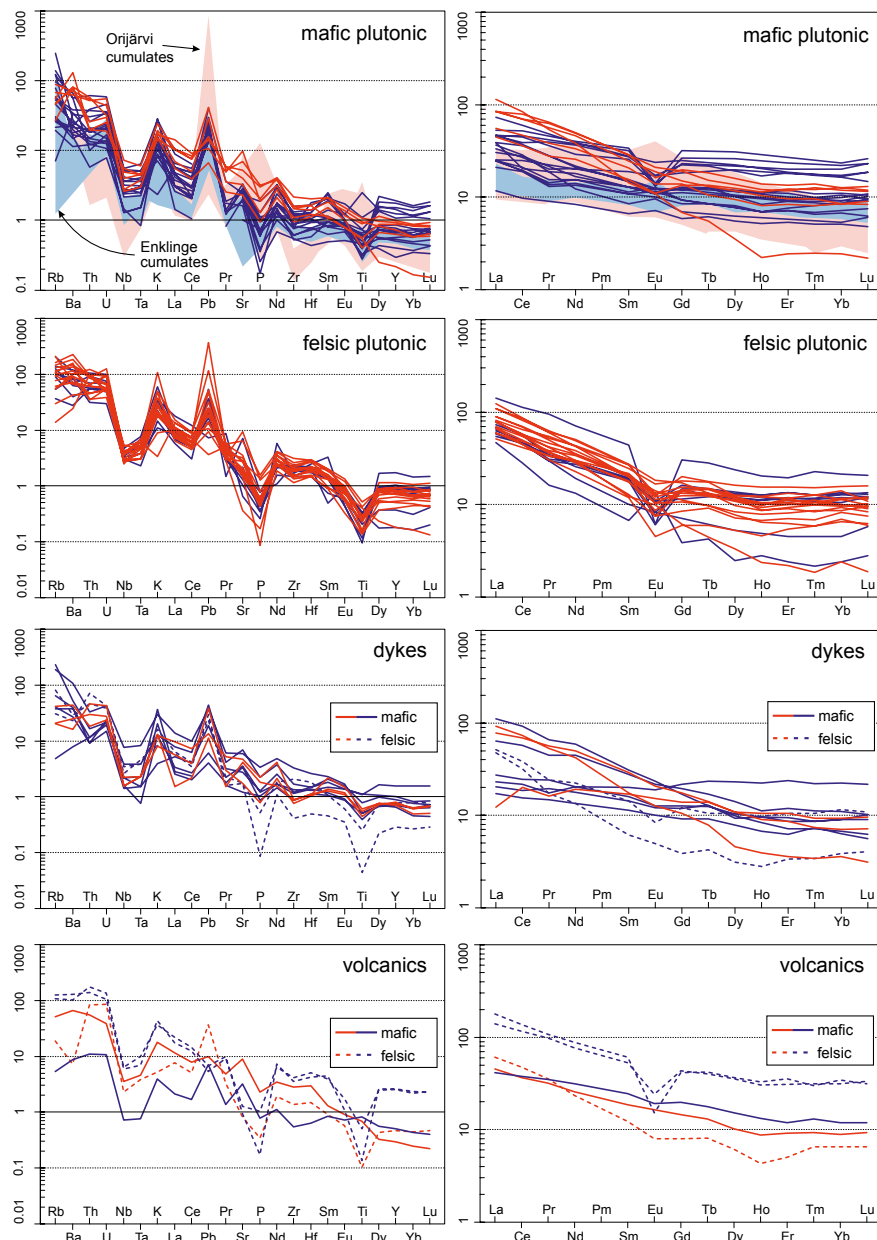


FIGURE 7. N-MORB normalized multi-element diagrams and chondrite normalized REE-diagrams. Normalizing values from Sun and McDonough (1989) and Boynton (1984), respectively. Colours as in Figure 4.

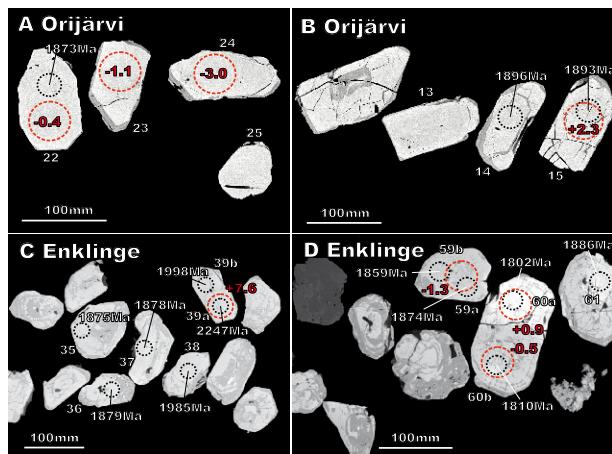


FIGURE 8. Back-Scattered Electron (BSE) images of representative zircons from the Orijärvi granodiorite (A and B) and from the Enklinge granodiorite (C and D). Black dashed circles represent U-Pb spots (25 μm) with $^{207}\text{Pb}/^{206}\text{Pb}$ age; red dashed circles represent Lu-Hf spots (50 μm) with initial $\epsilon_{\text{Hf}}(t)$ value. More detailed analysis data available in ELECTRONIC APPENDIX (Tables II and IV).

(95%; MSWD=0.78; $n=9/14$; Fig. 9E) and a weighted average $^{207}\text{Pb}/^{206}\text{Pb}$ age of 1848 ± 6 Ma (2 σ ; MSWD=1.14; $n=11/14$) was obtained on 11 analyses. An upper intercept age of 1850 ± 6 Ma (MSWD=0.6) were obtained using 12 analyses. The 1.85Ga age may indicate metamorphic resetting, although the younger zircons or zircon domains do not stand out as texturally different from the magmatic zircon. The three youngest analyses were omitted from the age calculations due to discordancy and/or slightly younger $^{207}\text{Pb}/^{206}\text{Pb}$ ages between 1818 and 1802 Ma.

Sm-Nd whole rock analyses

The mafic rocks from Enklinge have initial ϵ_{Nd} values (at 1882 Ma) from +1.9 to +2.9 whereas the felsic rocks exhibit values of +1.1 and +1.2. The depleted mantle model (T_{DM}) ages for the Enklinge samples fall between 2.15 and 2.12 Ga except for the sample 5-MJV06 (gabbro dyke) which shows a T_{DM} age of 2.0 Ga. The two mafic samples from Orijärvi have initial ϵ_{Nd} values (at 1892 Ma) of +1.1 and +2.0. The felsic rocks have values of -0.4 and +0.2. The T_{DM} ages for the Orijärvi samples are 2.35 and 2.16 Ga for the mafic rocks and 2.21 and 2.16 Ga for the felsic rocks. The Sm-Nd isotopic data are compared to previously published Nd-data from central Fennoscandian rocks in Figure 10.

Lu-Hf zircon analyses

In total, 37 analyses were performed on the Orijärvi granodiorite zircons. They show variation in the initial $^{176}\text{Hf}/^{177}\text{Hf}$ values between 0.28144 and 0.28165 corresponding to ϵ_{Hf} values between -4.7 and +2.6 with an average of -1.1 (at 1892 Ma).

A total of 21 Lu-Hf analyses were performed on the Enklinge granodiorite zircons. Eleven analyses were performed on zircons representing the age of crystallization, five on inherited zircons or inherited domains in zircons and five on zircons representing the younger ages. The magmatic zircons yielded initial $^{176}\text{Hf}/^{177}\text{Hf}$ values between 0.28150 and 0.28171 corresponding to initial ϵ_{Hf} values between -3.0 and +4.4 with an average value of 0 (at 1882 Ma). The individual $^{207}\text{Pb}/^{206}\text{Pb}$ age was used for the inherited and young zircon grains (ages varying from 2247 to 1951 Ma and 1859 and 1802 Ma, respectively) for the calculation of initial ϵ_{Hf} values. The inherited zircons exhibit initial $^{176}\text{Hf}/^{177}\text{Hf}$ values between 0.28156 and 0.28164, corresponding to initial ϵ_{Hf} values between +3.5 and +7.6. The initial $^{176}\text{Hf}/^{177}\text{Hf}$ values for the young zircons fall in the range 0.28150 to 0.28166, which translates into initial ϵ_{Hf} of -4.1 to +1.6. The Lu-Hf isotopic data are compared to previously published Hf-data from central Fennoscandian rocks in Figure 11.

DISCUSSION

Whole rock geochemistry

The Enklinge and Orijärvi igneous rocks have formed in a subduction-related volcanic arc environment (*e.g.* Colley and Westra, 1987; Ehlers and Lindroos, 1990; Kähkönen, 2005). The distinct subduction component can be seen in all the samples with pronounced troughs at Nb and Ta, and peaks at the subduction-mobile elements such as Ba, Th, U, Pb and Sr in the multi-element diagrams (Fig. 7). This feature is emphasised by fractionated REE pattern for the mafic rocks, as well as the felsic ones (Fig. 7). On the Th/Yb vs. Nb/Yb diagram all the mafic samples plot above the MORB-OIB array (Pearce and Peate, 1995; Pearce, 2008) and show Nb/Yb ratios ≥ 1.0 , suggesting an Active Continental Margin (ACM) setting rather than oceanic arc type magmatism (Fig. 12A). The same feature can be observed on the Th/Ta vs. Yb diagram (Schandl and Gorton, 2002), which shows ACM affinity for the felsic rocks (Fig. 12B). The wide range of rocks with intermediate and felsic compositions also support a continental setting as these form more easily from pre-existing continental crust (*e.g.* Tatsumi and Takahashi, 2006). However, part of the intermediate rocks is supposed to result from magma mixing (Fig. 3). The Nb/Zr vs. Nb/Ba diagram (Fig. 12C) indicates a SubContinental Lithospheric Mantle (SCLM) source for the mafic magmas.

The Orijärvi and the Enklinge rocks, especially the mafic ones, display some minor differences. The Enklinge rocks are slightly more enriched in HREEs and Cr, and depleted in LILEs, K_2O and P_2O_5 . This feature can be explained in different ways, for example: i) mantle

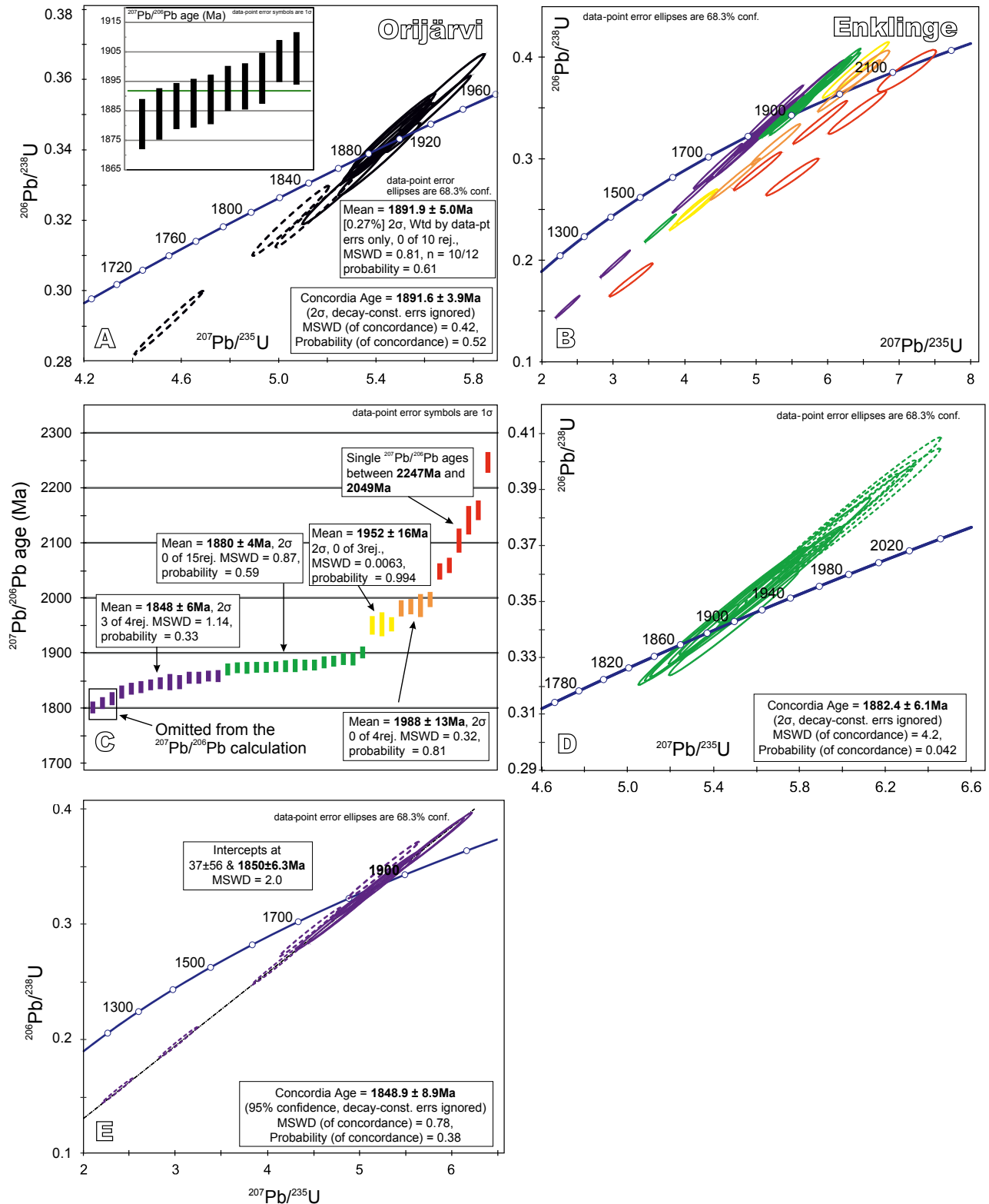


FIGURE 9. U-Pb and $^{207}\text{Pb}/^{206}\text{Pb}$ age diagrams and regression statistics for the zircon analyses. A) Data from the Orijarvi granodiorite (29a-MJV-06); B), C), D) and E) show data from the Enklinge granodiorite (3-MJV-06). Diagrams B) and C) represent all the Enklinge granodiorite U-Pb analyses. Different colours represent different age groups. See text for explanation.

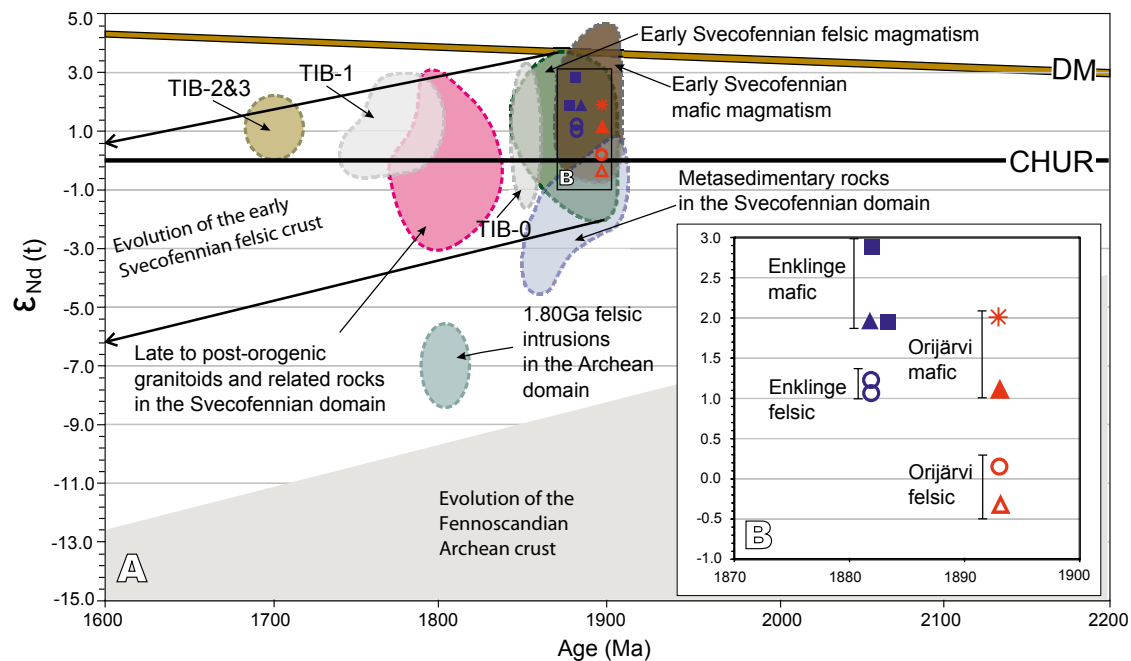


FIGURE 10. A) ϵ_{Nd} vs. Age diagram for the present samples and other relevant data from the Fennoscandian shield. CHUR=Chondritic Uniform Reservoir and DM=Depleted Mantle, after DePaolo (1981); TIB = Transscandinavian Igneous Belt; Evolution of the Fennoscandian Archean crust drawn after Andersson *et al.* (2001); Evolutionary trend for the early Svecofennian felsic crust drawn after Rutanen *et al.* (2011); Early Svecofennian mafic magmatism (Huhma, 1986, 1987; Patchett and Kouvo, 1986; Vaasjoki and Huhma, 1999; Makkonen and Huhma, 2007); Early Svecofennian felsic magmatism (Huhma, 1986; Patchett and Kouvo, 1986; Patchett *et al.*, 1987; Lahtinen and Huhma, 1997; Rämö *et al.*, 2001); Metasedimentary rocks in the Svecofennian domain (Huhma, 1987; Patchett *et al.*, 1987; Kumpulainen *et al.*, 1996; Lahtinen *et al.*, 2002); 1.8 Ga felsic intrusions in the Archean domain (Huhma, 1986); Late to post-orogenic granitoids and related rocks in the Svecofennian domain (Huhma, 1986; Patchett and Kouvo, 1986; Patchett *et al.*, 1987; Lahtinen and Huhma, 1997; Kurhila *et al.*, 2005; Andersson *et al.*, 2006a; Rutanen *et al.*, 2011); ca. 1.85 Ga TIB-0 mafic and felsic rocks (Andersson, 1997; Claeson and Andersson, 2000); ca. 1.80 Ga TIB-1 mafic and felsic rocks (Wilson *et al.*, 1985; Patchett *et al.*, 1987; Andersson, 1997; Wikström and Andersson, 2004; Andersson *et al.*, 2004, 2007; Johansson *et al.*, 2006; Rutanen and Andersson 2009); ca. 1.70 Ga TIB-2&3 felsic rocks (Wilson *et al.*, 1985; Patchett *et al.*, 1987; Heim *et al.*, 1996; Nyström 1999; Appelquist *et al.*, 2011). B) Close-up of the current data. Symbols as in Figure 4, same units as in A).

heterogeneity (*i.e.* depleted or enriched magma sources), ii) variations in the materials being contributed by the subducting slab to the mantle wedge, iii) different degrees of partial melting in the mantle wedge, or iv) assimilation of the surrounding crust during magma ascent. These processes are difficult to distinguish from each other. However, different element ratios can give a hint on the petrogenesis of the mafic rocks. A ratio of highly fluid-mobile to less fluid-mobile or fluid-immobile elements (*e.g.* Sr/Ce, Ba/Nb, Ba/Th and U/Th; Carr *et al.*, 1990; Kessel *et al.*, 2005; Pearce *et al.*, 2005; Wehrmann *et al.*, 2014) shows only very limited subduction additions and low degree of fluid flux from the subducting slab to the mantle wedge. Based on the ratio of more incompatible to less incompatible elements (*e.g.* Sm/Lu, La/Yb, La/Sm, Nb/Y; Carr *et al.*, 1990; Yang *et al.*, 2007; Wehrmann *et al.*, 2014), the Enklinge rocks tend to show a higher degree of partial melting (Fig. 13A). Thus, different degrees of partial melting may explain some compositional differences between Orijärvi and Enklinge.

Crustal contamination is estimated through Nb/Th ratio combined with Nb/La ratio (Fig. 13B) which suggests that some of the Orijärvi rocks are more affected by such a

process. Part of this is the result of magma mixing between mafic and felsic magmas, something which is also supported by field observations (Fig. 3) and visible in the rather high SiO₂ content of a few contaminated mafic rocks. We suggest that the small differences in the mafic rocks in the study areas are due to higher degree of partial melting in Enklinge and slightly more intense magma mixing between mafic and felsic magma in Orijärvi. However, scattered and partly overlapping data between the study areas hinders further interpretations.

The felsic rocks of both study areas are similar which indicate similar petrogenesis. The ASI mostly below 1.1, Na₂O over 3.2 wt.% with a few exceptions, low K₂O/Na₂O ratios and abundant mafic magmatic enclaves suggest that the felsic rocks are I-type (Fig. 5; Table I; *e.g.* Chappell and White, 1974) with an amphibolitic source in the granite source diagram (Patiño Douce, 1999; Fig. 14). This suggests that the felsic rocks have formed by partial melting of mafic lithosphere and that no large scale sedimentary components have been involved in the magma generation.

The cumulate rocks from Enklinge and Orijärvi share the same ACM signature as the major group of the mafic rocks

(Fig. 12A). However, they show very different geochemical features. The likely cause for the primitive signature of the Enklinge cumulates is accumulation of MgO-rich minerals like hornblende and pyroxene ($\pm$ olivine). This is supported by low Na_2O and Al_2O_3 , and moderate CaO contents. The characteristic geochemical signature of the Orijärvi layered intrusion rocks can be explained by mineral accumulation processes in a magma chamber. Different types of cumulates can be found within the layered intrusion (Sarapää *et al.*, 2005) ranging from hornblendites to garnet-bearing gabbro and anorthosite, the latter being absent in Enklinge. In addition, the Orijärvi samples show much higher Eu/Eu^* ratios compared to the Enklinge cumulates suggesting overall plagioclase accumulation within the layered intrusion. The Orijärvi sample 45-MAV-02 is extremely rich in P_2O_5 which can be explained by accumulation of apatite, whereas the sample 22-MJV-06 is high in TiO_2 due to titanite enrichment. Johansson *et al.* (2012) have studied arc cumulates of similar age from the Roslagen area of East-central Sweden, which show some similar features. For

example, the Enklinge primitive cumulates are comparable to the olivine and pyroxene cumulates whereas the Orijärvi layered intrusion resembles the plagioclase cumulates of the Roslagen area. Moreover, the Enklinge cumulates might represent a low intersection of a magma chamber (*i.e.* early fractionates and/or bottom cumulates of a magma chamber) whereas the Orijärvi cumulates suggest later fractionation processes and a higher intersection.

In summary, the co-genetic relation between intrusive and extrusive rocks is supported by their similar whole rock compositions. In addition, the coeval relation between mafic and felsic magmatism is supported by field observations.

Age data

The crystallization age of $1892 \pm 4 \text{ Ma}$ for the Orijärvi granodiorite is supported by the previously obtained TIMS and SIMS ages of $1891 \pm 13 \text{ Ma}$ (Huhma, 1986) and

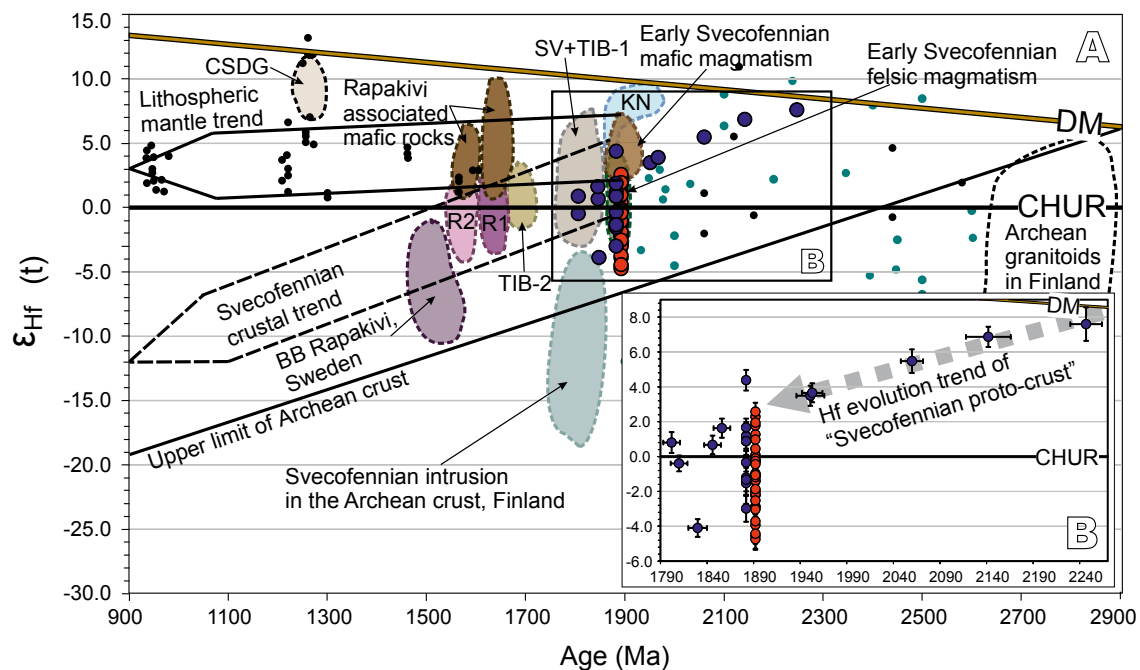


FIGURE 11. A) ϵ_{Hf} vs. Age diagram for the present samples and other relevant data from the Fennoscandian shield. Orijärvi granodiorite Hf data are represented by red dots and Enklinge granodiorite Hf data by blue dots. CHUR=chondritic uniform reservoir (Bouvier *et al.*, 2008); DM=Depleted Mantle (Griffin *et al.*, 2000); The Hf evolution trend for Paleoproterozoic Fennoscandian lithospheric mantle ($\epsilon_{\text{Hf}}(1.90)=+4.5 \pm 2.5$ and $^{176}\text{Lu}/^{177}\text{Hf} \approx 0.0315$) drawn after Andersen *et al.* (2009), modified by Andersson *et al.* (2011); The Hf evolution trend for the Svecofennian crust $\epsilon_{\text{Hf}}(1.90)=+2 \pm 3$ and $^{176}\text{Lu}/^{177}\text{Hf} \approx 0.015$ (Andersen *et al.*, 2009); Upper limit of Fennoscandian Archean crust (Andersen *et al.*, 2009); Archean granitoids in Finland (Patchett *et al.*, 1981; Lauri *et al.*, 2011); Knaften arc (KN; Guitreau *et al.*, 2014); Early Svecofennian mafic intrusion (Patchett *et al.*, 1981; Andersson *et al.*, 2011); Early Svecofennian felsic magmatism (Andersen *et al.*, 2009; Heinonen *et al.*, 2010; Andersson *et al.*, 2011; this study); Syn to late Svecofennian granitoids and Transscandinavian Igneous Belt generation 1 (SV+TIB1; Patchett *et al.*, 1981; Vervoort and Patchett, 1996; Andersen *et al.*, 2009; Andersson *et al.*, 2011; Johansson *et al.*, 2015); Transscandinavian Igneous Belt generation 2 (TIB2; Andersen *et al.*, 2009); Rapakivi granites from South-East Finland (R1), South-West Finland (R2) and associated mafic rocks (Heinonen *et al.*, 2010); Rapakivi granites from Bothnian Basin (BB), Sweden (Andersson *et al.*, 2011); Central Scandinavian Dolerite Group (CSDG; Patchett *et al.*, 1981; Söderlund *et al.*, 2006); Black dots represent mafic intrusions in the Fennoscandian shield (Patchett *et al.*, 1981; Söderlund *et al.*, 2005); Turquoise dots represent inherited zircons/cores from Svecofennian felsic rocks (Andersen *et al.*, 2009; Kurhila *et al.*, 2010; Andersson *et al.*, 2011). B) Close-up of the present data. The grey arrow indicates an extension for the Svecofennian crustal Hf trend and a possible Hf evolution for the juvenile "Svecofennian proto-crust" based on a linear regression of the inherited zircon data from the Enklinge granodiorite ($\epsilon_{\text{Hf}}(2.25)=+8 \pm 3$ and $^{176}\text{Lu}/^{177}\text{Hf} \approx 0.012$). The error bars are 2σ for ϵ_{Hf} values and for concordia ages (magmatic ages), and 1σ for individual $^{207}\text{Pb}/^{206}\text{Pb}$ ages.

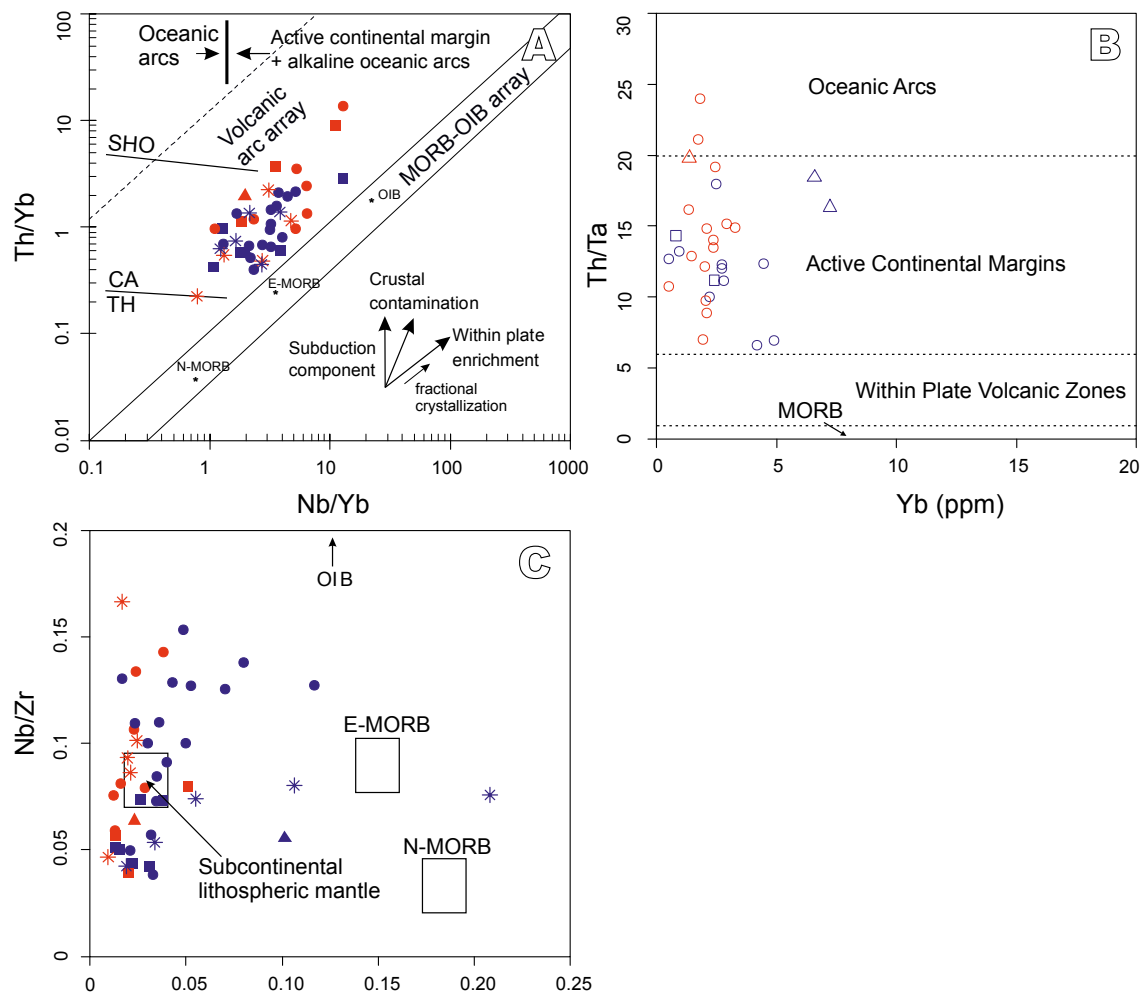


FIGURE 12. Geotectonic setting of A) the mafic rocks (Pearce, 2008) and B) the felsic rocks (Schandl and Gorton, 2002). C) Source of the mafic rocks (Hooper and Hawkesworth, 1993). OIB=Ocean Island Basalt (Sun and McDonough, 1989), E-MORB=Enriched Mid-Ocean Ridge Basalts (Sun and McDonough, 1989), N-MORB=Normal Mid-Ocean Ridge Basalts (Sun and McDonough, 1989), subcontinental lithospheric mantle (Hooper and Hawkesworth, 1993; Albarède, 2005). Symbols as in Figure 4.

1898±9Ma (Väisänen *et al.*, 2002), as well as the previous TIMS age for the adjacent Orijärvi rhyolite (1895±3Ma; Väisänen and Mänttari, 2002). In contrast, several zircon populations were identified in the Enklinge granodiorite. The age 1882±6Ma for the crystallization is the same as the previous TIMS age 1882±15Ma (Suominen, 1987) and the SIMS age 1885±6Ma for the adjacent Enklinge rhyolite (Ehlers *et al.*, 2004). The inherited zircons have several different ages between 2.25 and 1.95Ga. The oldest grains, with ages between 2.25 and 2.05Ga, probably do not belong to same population but are derived from different sources. The younger inherited zircons might represent two different magmatic source rocks with ages of 1988±13Ma and 1952±16Ma.

The origin of the inherited zircons in the Enklinge granodiorite is unclear but the age range is similar to that of the inherited zircon populations discovered from central

Fennoscandian meta-sedimentary rocks (Huhma *et al.*, 1991; Claesson *et al.*, 1993; Lahtinen *et al.*, 2002). Ehlers *et al.*, (2004) found similar zircon ages, *ca.* 2040Ma, for the Kõkar granodiorite (Fig. 1B), including the oldest xenocrystic core of 3136Ma. The Sarmatian segment, the southernmost crustal segment of the East European craton, has been proposed to be the provenance for the 2.10–1.95Ga zircon populations (Lahtinen *et al.*, 2002). Recently, Samsonov *et al.* (2016) reported *ca.* 2.0Ga ages on juvenile volcanic rocks and granitoids from the southern part of the Central Russian Fold Belt, in the central part of the East European craton, now covered by platform sediments, which could also be a source. Another explanation is the possible presence of juvenile, *ca.* 2.20–1.93Ga “proto-Svecofennian” crust at depth, predating the early Svecofennian (1.90–1.86Ga) magmatism (*e.g.* Lahtinen and Huhma, 1997; Andersson *et al.*, 2006b, 2011). This proto-crust is not exposed at the present erosion level but it could have been a source for the granodioritic melts.

The interpretation of the youngest zircon ages is somewhat ambiguous due to the heterogeneous zircon morphologies. The youngest zircons, with $^{207}\text{Pb}/^{206}\text{Pb}$ ages between 1859 and 1802Ma, are considered to represent a metamorphic event. The concordia age of $1849 \pm 9\text{Ma}$ is similar to the $^{207}\text{Pb}/^{206}\text{Pb}$ age of $1848 \pm 6\text{Ma}$ and the upper intercept age of $1850 \pm 6\text{Ma}$ which suggest a metamorphic phase at *ca.* 1850Ma in the Enklinge area. The three youngest analyses were omitted from the age calculations but they show $^{207}\text{Pb}/^{206}\text{Pb}$ ages around 1810Ma, and may indicate a second metamorphic event. Alternatively, since the $^{207}\text{Pb}/^{206}\text{Pb}$ ages for all the metamorphic zircons form a continuous trend between 1859 and 1802Ma they could indicate incomplete resetting of the “U–Pb clock” during a single metamorphic event at around 1800Ma, or even later. A third alternative, which does not exclude the two previous options, would be a continuous Pb loss after 1.86Ga due to late geological event(s) or long-term diffusive radiogenic Pb loss (*cf.* Whitehouse *et al.*, 1999; Kusiak *et al.*, 2013).

Metamorphic ages around 1.85Ga from southern Svecofennia are scarce as the metamorphic peak is usually dated at between 1.83 and 1.81Ga (Korsman *et al.*, 1999; Väisänen *et al.*, 2002; Mouri *et al.*, 2005; Andersson *et al.*, 2006b; Högdahl *et al.*, 2008). However, Torvela *et al.* (2008) obtained a SIMS zircon age of $1850 \pm 12\text{Ma}$ for the metamorphic rims from a granodioritic gneiss, and a TIMS titanite age of $1842 \pm 8\text{Ma}$ for a wide mylonite zone at Kökar in the SW Finnish archipelago (Fig. 1B). This gives a strong evidence for a *ca.* 1.85Ga metamorphic phase in the study area. In addition, *ca.*

1.86–1.84Ga, intraorogenic mafic magmatism has been described from southern Finland (Pajunen *et al.*, 2008; Väisänen *et al.*, 2012a; Nevalainen *et al.*, 2014), which suggests that high heat flux had already started at *ca.* 1.85Ga (Skyttä and Mänttari, 2008; Kurhila *et al.*, 2010; Väisänen *et al.*, 2012a, 2012b). Magmatic activity and a metamorphic phase at 1.87–1.85Ga have also been recognized in Bergslagen, Sweden (*e.g.* Stephens and Andersson, 2015; Johansson and Stephens, 2017). The nearest described *ca.* 1.85Ga coeval mafic and felsic magmatism is from Korppoo, 50km East of Enklinge (Väisänen *et al.*, 2012a). The possible late metamorphic age of *ca.* 1.81–1.80Ga is based on only three analyses from two zircons. However, Torvela *et al.* (2008) found evidence for a *ca.* 1.80–1.79Ga metamorphic phase in the same area, and Stephens and Andersson (2015) have described such a late metamorphic pulse in Sweden. These observations could justify a late metamorphic event at *ca.* 1.81–1.80Ga in the Enklinge area. Based on present and previous studies, we thus suggest that two metamorphic events, at *ca.* 1.85Ga and *ca.* 1.80Ga, occurred in the Enklinge region.

The lack of inherited zircons and xenocrystic cores is the most obvious feature in the Orijärvi granodiorite (*cf.* Väisänen *et al.*, 2002), although 2.12–1.93Ga zircons have been found in the Orijärvi meta-greywacke lying stratigraphically above the Orijärvi granodiorite (Claesson *et al.*, 1993). The BSE-images reveal a few cores or core-like structures in zircons but they were too small to be analysed with a $25\mu\text{m}$ spot size. In any case, the inherited zircon material in the Orijärvi granodiorite is scarce. The new and the previously published age data

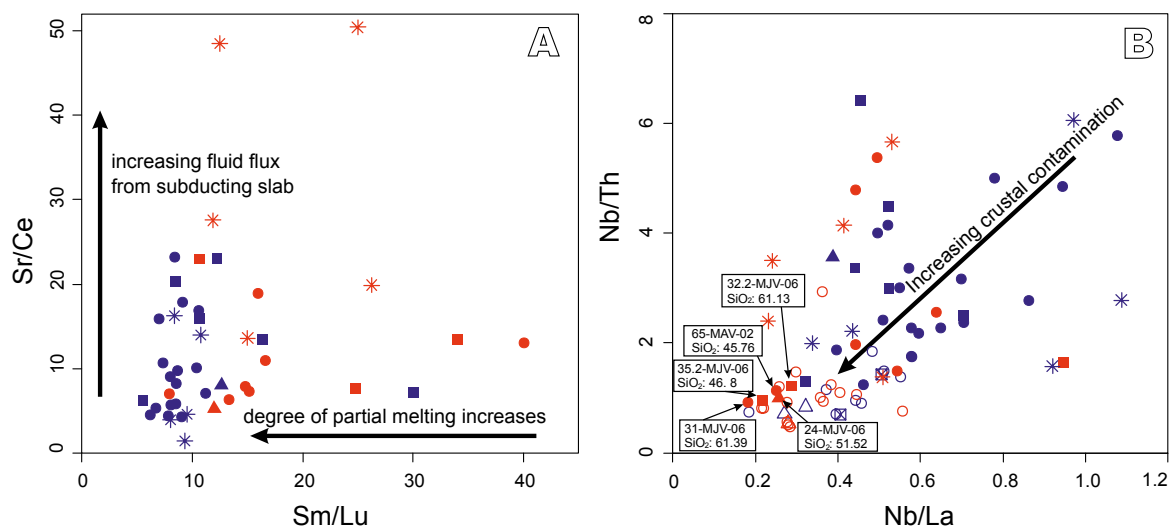


FIGURE 13. A) Partial melting and subducting slab fluid signal in the mafic rocks. Sm/Lu ratio decreases with increasing partial melting, while Sr/Ce ratio increases with increasing amount of fluids derived from subducting slab. B) Nb/Th vs. Nb/La diagram suggesting crustal contamination in samples with low values in both ratios. The felsic rocks and SiO₂ content of selected mafic samples are included in the diagram to visualise magma mixing between mafic and felsic magmas. Symbols as in Figure 4.

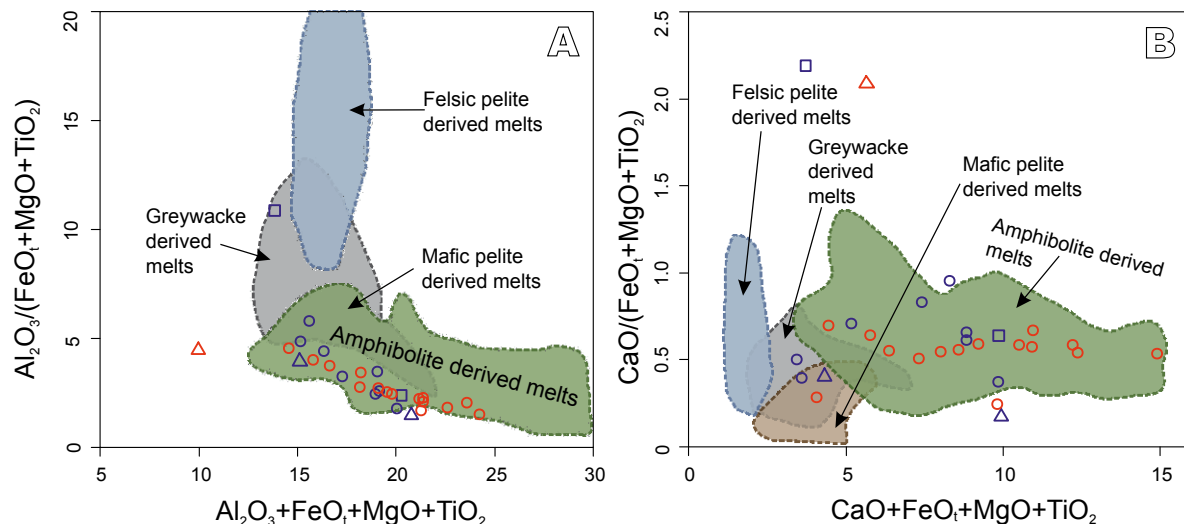


FIGURE 14. Sources for felsic rocks after Patiño Douce (1999). The “Mafic pelite derived melts” in diagram A) is exactly at the cross section of the “Greywacke derived melts” and the “Amphibolite derived melts” areas. Symbols as in Figure 4.

support a co-genetic relationship between the volcanic and plutonic rocks in both localities.

Sm-Nd and Lu-Hf data

A rather homogeneous and geographically extensive “mildly depleted” mantle reservoir has been proposed as a source for the juvenile (2.10–) 1.90–1.86Ga Svecofennian crust based on both the whole rock Nd- (*e.g.* Lahtinen and Huhma, 1997; Andersson *et al.*, 2007; Rutanen and Andersson, 2009; Rutanen *et al.*, 2011) and the single grain zircon Hf-isotope data (*e.g.* Andersen *et al.*, 2009; Andersson *et al.*, 2011; Rutanen *et al.*, 2011; Johansson *et al.*, 2015). The characteristic mild depletion might be a result of prolonged depletion followed by subduction-related enrichment but the extent of this mantle source, both spatial and temporal, is poorly known.

The initial ϵ_{Nd} values between +1.1 to +2.9 suggest that the mafic rocks from both localities are rather juvenile and have been derived from the mildly depleted mantle source (Fig. 9). The sample 36-MJV-06 (basalt) from Orijärvi shows initial ϵ_{Nd} value of +1.1, which is slightly lower compared to that of the other mafic rocks. This small discrepancy could be attributed to small scale variations in the mantle source (*cf.* Rutanen *et al.*, 2011; Dahlin *et al.*, 2014) or magma mixing/crustal contamination. The sample 22-MJV-06 is from the Orijärvi layered intrusion and, although it has a different geochemical composition compared to the other mafic rocks, its Nd isotopic composition proves that it has been derived from a similar magma source. The Orijärvi mafic rocks show slightly older T_{DM} ages compared to the Enklinge rocks.

Somewhat more enriched (near-chondritic) initial ϵ_{Nd} values for the felsic rocks from both localities suggest involvement of crustal material in their magma genesis. This is best explained by the formation of the felsic rocks by partial melting of the juvenile Svecofennian proto-crust whereas the mafic rocks are derived from the mildly depleted upper mantle. It is unlikely that the near-chondritic ϵ_{Nd} values for the felsic rocks are due to subducted hydrous sediments because lowering the ϵ_{Nd} from depleted values to values around zero would require a huge sediment input via subduction (*cf.* Hawkesworth *et al.*, 1991), which is not supported by the whole rock geochemical data. In addition, Lahtinen and Huhma (1997) considered only a minor part of the Nd in central Svecofennia to be derived from subducted sediments with the major contribution coming from subducted altered MORB. The small but systematic difference in initial ϵ_{Nd} between felsic and mafic rocks does not support the evolution of felsic rocks via differentiation from the mafic magmas.

The Enklinge mafic rocks show slightly higher initial ϵ_{Nd} values than the Orijärvi mafic rocks which suggests a slightly more primitive signature of the former. This is supported also by the initial ϵ_{Nd} values: around +1 in the felsic rocks from Enklinge and around zero from Orijärvi.

The Hf isotopic data from the two granodiorites are in accordance with the Nd isotopic data. However, the Hf isotopes yield a more detailed view of the magma generation. The average initial ϵ_{Hf} values for the magmatic zircons are -1.1 and 0 in the Orijärvi and Enklinge granodiorites, respectively, which suggests that both granodiorites are derived mainly from crustal sources (Fig. 10). The zircons have captured some variation in the initial ϵ_{Hf} values; the

Orijärvi granodiorite shows a range of 7.3 ϵ -units (at 1892Ma) and the Enklinge shows a range of 7.4 ϵ -units (at 1882Ma). The variation exceeds the external precision of our Hf isotope analyses. This suggests a minor mixing in the magma genesis between mildly depleted parental magma (slightly positive ϵ_{Hf} values) and a partial melt from crustal sources (slightly negative ϵ_{Hf} values), which is considered the major source for the felsic rocks. The mafic parental magmas have probably mostly provided the heat and only small fractions of material to the formation of the felsic rocks.

Andersen *et al.* (2009) defined the Hf evolution trend for the Svecofennian crustal rocks ($\epsilon_{\text{Hf}}(1.90)=+2\pm3$ and $^{176}\text{Lu}/^{177}\text{Hf}\approx0.015$) and for the mildly depleted mantle source ($\epsilon_{\text{Hf}}(1.90)=+3\pm3$ and $^{176}\text{Lu}/^{177}\text{Hf}\approx0.033$). These trends were slightly modified by Andersson *et al.* (2011). The inherited zircons from Enklinge define a trend towards a more depleted source with increasing age between 1.95 and 2.25Ga which suggests their juvenile origin and support the presence of Svecofennian juvenile proto-crust. Linear regression of the data suggest an evolutionary trend of $\epsilon_{\text{Hf}}(2.25)=+8\pm3$ and $^{176}\text{Lu}/^{177}\text{Hf}\approx0.012$ similar to that obtained by Andersen *et al.* (2009) for Svecofennian crust, and by Taylor and McLennan (1995) and Wedepohl (1995) for average continental crust ($^{176}\text{Lu}/^{177}\text{Hf}\approx0.0113$). No clear Archean “contamination” can be identified in the inherited zircons based on the Hf isotope composition. However, it remains uncertain why the proto-crust trend intercepts the magmatic zircons at the upper end of their compositional range. It may suggest that the inherited zircons (and the upper end of the magmatic zircons) represent relatively juvenile lower proto-crust or oceanic crust while a more evolved continental proto-crust would have contributed to the lower end of the magmatic zircon spectrum. The linear trend of the inherited zircons is continued by metamorphic zircons, which have captured a continuum of the Hf-isotope evolution.

Implications for the early Svecofennian crustal growth

During the opening of the proposed pre-Svecofennian sea at *ca.* 2.2–2.0Ga (*cf.* Nironen 1997, Lahtinen *et al.*, 2005; Hermansson *et al.*, 2008; Guitreau *et al.*, 2014) the rift-related mafic magmatism (Vuollo and Huhma, 2005) and/or ocean floor generation (Guitreau *et al.*, 2014) resulted in depletion of the subcontinental lithospheric mantle beneath the Svecofennian domain (Andersson *et al.*, 2006a, 2007, 2011). The depletion was followed by a subduction-related enrichment and an early arc (proto-crust) formation at *ca.* 2.1–1.91Ga, which resulted in characteristic mildly depleted values in the SCLM (*e.g.* initial ϵ_{Nd} values chondritic to mildly positive, LILE and LREE enrichment, HFSE depletion; Lahtinen and Huhma, 1997; Andersson *et al.*, 2006a, 2011; Andersen *et al.*, 2009; Rutanen *et al.*, 2011; Johansson *et al.*, 2012; Johansson and Hålenius, 2013).

The initial ϵ_{Nd} values and average initial ϵ_{Hf} values from both studied granodiorites match previously published data on Svecofennian rocks, and support the model with an extensive mildly depleted mantle source beneath central Fennoscandia at 1.89–1.88Ga. In addition, the Enklinge inherited zircons U–Pb and Hf isotope data suggest the presence of unexposed Svecofennian juvenile proto-crust. The proto-crust hypothesis is also supported by the whole rock geochemical data, which show clear continental arc affinities for all the samples as well as by the bimodal nature of the magmatism.

CONCLUSIONS

i) The Enklinge and Orijärvi volcanic rocks have formed in a continental volcanic arc environment. The intrusive and extrusive rocks are co-genetic, and the felsic and mafic rocks are coeval but not co-magmatic based on field observations, geochemical, age and isotopic data in both study areas. The differences between the Orijärvi and Enklinge mafic rocks are most likely due to a more extensive partial melting in the Enklinge area or a larger crustal contamination in the Orijärvi area.

ii) The age of the Orijärvi granodiorite was determined to be $1892\pm4\text{Ma}$, and the age of the Enklinge granodiorite to be $1882\pm6\text{Ma}$. Several inherited zircons were found from the Enklinge granodiorite ranging from 2.25 to 1.95Ga. Especially, the 1.99 and 1.95Ga populations are assumed to represent ages within the proposed Svecofennian proto-crust. A metamorphic phase occurred at *ca.* 1.85Ga in the Enklinge area, while the last metamorphic activity in the same area probably occurred at *ca.* 1.80Ga.

iii) The mafic rocks from both localities show mildly depleted mantle signatures with initial ϵ_{Nd} values between +1.1 and +2.9, and exhibit T_{DM} ages between 2.35 and 2.0Ga. The felsic rocks exhibit initial ϵ_{Nd} values of -0.4 and +0.2 for Orijärvi, and +1.1 and +1.2 for Enklinge with T_{DM} ages between 2.2–2.1Ga for both localities, which suggests larger crustal contribution in their petrogenesis.

iv) The Lu–Hf data from the Orijärvi granodiorite (average initial ϵ_{Hf} -1.1 at 1892Ma) and the Enklinge granodiorite (average initial ϵ_{Hf} 0 at 1882Ma) are in accordance with the Nd data from the same rocks. The variation in the ϵ_{Hf} (*ca.* 7 ϵ units for both samples) is assumed to result from mixing between depleted parental mantle magmas and partial melts from crustal sources.

v) The evolutionary trend for the Enklinge inherited zircons, $\epsilon_{\text{Hf}}(2.25)=+8\pm3$ and $^{176}\text{Lu}/^{177}\text{Hf}\approx0.012$, adds more evidence to the presence of Svecofennian proto-crust. The data suggest that the proto-crust originated from a juvenile mantle source.

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ELECTRONIC APPENDIX I

ANALYTICAL METHODS

Whole rock geochemistry

A total of 75 whole-rock samples were studied, of which 34 were from Orijärvi and 41 from Enklinge. The data include plutonic, dyke and volcanic rock samples. The Orijärvi and part of the Enklinge samples were analysed at Acme Analytical Laboratories Ltd. (Acme) in Vancouver, Canada (*cf.* Table I). The samples were pulverised in a mild steel swing mill and, after the LiBO_2 fusion and HNO_3 dilution, the major elements, Cr, and Sc were analysed by inductively coupled plasma-optical emission spectrometry (ICP-OES). The other trace elements were analysed by inductively coupled plasma-mass spectrometry (ICP-MS). The analytical precision is 1-5% for the major oxides and $\pm 10\%$ for the other elements. Part of the Enklinge samples were analysed at Activation Laboratories Ltd. (Actlabs), Ancaster, Canada, and part at Genalysis in Perth, Australia. At Actlabs the samples were pulverised in a mild steel swing mill. After the lithium metaborate/tetraborate fusion, the major elements were analysed by ICP-OES, and the trace elements by ICP-MS. The relative standard deviations for replicate analyses are $\leq 3\%$ for major elements and $\leq 5\%$ for trace elements. At Genalysis the samples were pulverised in a mild steel swing mill and, after lithium metaborate/tetraborate fusion the major elements, Cr, Ni, Sc and V were analysed by ICP-OES, and other trace elements by ICP-MS. The analytical precision is 1-5% for the major oxides and $\pm 10\%$ for the trace elements. The major and trace element data for the study areas are presented in Table I.

U-Pb zircon analyses

Two samples, one from each study area, were selected for U-Pb spot analyses on zircon in order to determine their crystallization ages and to perform Lu-Hf analyses on same zircon grains. The grains were separated using the standard procedure with crushing, panning, heavy liquid separation, magnetic separation and hand picking. The analytical spots were selected on the basis of BSE-images conducted using a LEO 1530 Gemini scanning electron microscope at Åbo Akademi University Finland (Orijärvi granodiorite) and a JEOL JSM-7100F FE-SEM at the Finnish Geosciences Research Laboratory at the Geological Survey of Finland in Espoo (Enklinge granodiorite).

The Orijärvi granodiorite U-Pb dating analyses were performed using a Nu Plasma AttoM single collector ICP-MS at the Geological Survey of Finland in Espoo connected

to a Photon Machine Excite laser ablation system. Samples were ablated in He gas (gas flows = 0.4 and 0.11/min) within a HelEx ablation cell (Müller *et al.*, 2009). The He aerosol was mixed with Ar (gas flow = 0.9l/min) prior to entry into the plasma. The gas mixture was optimized daily for maximum sensitivity. Typical ablation conditions were: beam diameter: 25 μm , pulse frequency: 5Hz, beam energy density: 2J/cm². A single U-Pb measurement included a short pre-ablation, 15s of on-mass background measurement, followed by 30s of ablation with a stationary beam. ^{235}U was calculated from the signal at mass 238 using the natural $^{238}\text{U}/^{235}\text{U}=137.88$. Mass number 204 was used as a monitor for common ^{204}Pb . In an ICP-MS analysis, ^{204}Hg mainly originates from the He supply. The observed background counting-rate on mass 204 was 150-200cps, and has been stable at that level over the last two years. The contribution of ^{204}Hg from the plasma was eliminated by on-mass background measurement prior to each analysis. Age related common lead (Stacey and Kramers, 1975) correction was used when the analysis showed common lead contents significantly above the detection limit (*i.e.* >50cps). Signal strengths on mass 206 were typically 100,000cps, depending on the uranium content and age of the zircon.

Calibration standard GJ-1 (609 ± 1 Ma; Belousova *et al.*, 2006) and in-house standard A382 (1877 ± 2 Ma, Huhma *et al.*, 2012) were run at the beginning and end of each analytical session, and at regular intervals during sessions. Raw data were corrected for the background, laser induced elemental fractionation, mass discrimination and drift in ion counter gains, and reduced to U-Pb isotope ratios by calibration to concordant reference zircons, using the program Glitter (Van Achterbergh *et al.*, 2001). Further data reduction including common lead correction and error propagation was performed using an in-house Excel spreadsheet. Errors include measured within-run errors (SD) and quadratic addition of reproducibility of standard (SE). To minimize the effects of laser-induced elemental fractionation, the depth-to-diameter ratio of the ablation pit was kept low, and isotopically homogeneous segments of the time-resolved traces were calibrated against the corresponding time interval for each mass in the reference zircon.

The Enklinge granodiorite zircon U-Pb dating analyses were performed using a Nu Plasma HR multicollector ICP-MS at the Geological Survey of Finland in Espoo using a technique very similar to Rosa *et al.* (2009), except that a Photon Machine Analyte G2 laser ablation system was used. The analytical conditions were similar to the Nu

Plasma AttoM single collector ICP-MS described above, except: Ar gas flow rate was set to 0.8L/min, beam diameter was 20µm and beam energy density was 0.55J/cm². A single U-Pb measurement included 30s of on-mass background measurement, followed by 60s of ablation with a stationary beam. Masses 204, 206 and 207 were measured in secondary electron multipliers, and 238 in an extra high mass Faraday collector. The geometry of the collector block does not allow simultaneous measurement of ²⁰⁸Pb and ²³²Th. Ion counts were converted and reported as volts by the Nu Plasma time-resolved analysis software. The technique for calculating ²³⁵U and monitoring common ²⁰⁴Pb was similar to AttoM.

The same calibration procedure with the same zircon standards were used as described above but raw data were corrected using protocols adapted from Andersen *et al.*, (2004) and Jackson *et al.*, (2004). The calculations were performed off-line, using an interactive spreadsheet program written in Microsoft Excel/VBA by T. Andersen (Rosa *et al.*, 2009).

Plotting of the U-Pb isotopic data and age calculations were performed using the Isoplot/Ex3 program (Ludwig, 2003). All, except one (calculated with 95% confidence level), ages were calculated with 2σ errors and without decay constants errors. Data-point error ellipses in the figures are at the 2σ level. The concordant age offset from ID-TIMS ages for several samples including zircon 91500 (1066Ma) and A382 (1877±2Ma; Patchett and Kouvo, 1986, and Huhma *et al.*, 2012) does not exceed 0.5%. The U-Pb isotopic data from the two analysed samples are presented in Table II.

Sm-Nd whole rock analyses

The Sm-Nd analyses were performed on nine samples, out of which four were from Orijärvi and five from Enklinge. The whole-rock powders of the investigated rocks have been analysed for their Sm and Nd contents, and Nd isotope compositions at the Laboratory for Isotope Geology of the Swedish Museum of Natural History. For the analyses, 150–200mg of rock powder was mixed with an appropriate amount of mixed ¹⁴⁷Sm–¹⁵⁰Nd spike, and dissolved in HF and HNO₃ (concentrated 10:1 mixture) in teflon capsules in an oven at 205°C for a few days. After evaporation, the samples were redissolved, first in 5ml 6M HCl at 205°C overnight, and then in 1ml 2.5M HCl at 60°C overnight. After centrifuging to obtain a clear solution, REE as a group was separated from the solution using standard cation exchange procedures with HCl and HNO₃ as media. The REE fractions were evaporated and redissolved in 0.05M HNO₃, and Sm and Nd separated from each other with HCl using the Ln-spec method (Pin and Zalduegui, 1997).

Samarium was analysed in static mode, and neodymium in multi-dynamic mode on a Finnigan MAT261 multicollector mass spectrometer, with corrections for isobaric interferences and fractionation as reported in the footnotes to Table 3. Results of repeated runs of the La Jolla Nd-standard are also reported there. Sm and Nd concentrations, and Nd isotope compositions were computed from the spiked analyses. T_{CHUR} Nd model ages have been calculated according to Jacobsen and Wasserburg (1984), and T_{DM} model ages according to the Depleted Mantle curve of DePaolo (1981). The Sm-Nd isotopic data from the nine samples are presented in Table III.

Lu-Hf zircon analyses

The in-situ zircon Lu-Hf isotope analyses were performed on the same or adjacent domains of the grains on which the U-Pb dating was done. The analyses were carried out using the Nu Plasma HR multicollector ICP-MS at the Geological Survey of Finland in Espoo using a technique very similar to Heinonen *et al.*, (2010) except that a Photon Machine Analyte G2 laser ablation system was used. The samples were ablated in He gas (gas flows=0.4 and 0.1L/min) within a HelEx ablation cell (Müller *et al.*, 2009). All analyses were made in static ablation mode using the following parameters: beam diameter: 50µm; pulse frequency: 5Hz; beam energy density: 3.4J/cm². Each ablation was preceded by a 30s on-mass background measurement. The MC-ICP-MS was equipped with 9 Faraday detectors and amplifiers with 10¹¹Ω resistors. During the ablation, the data were collected in static mode (¹⁷²Yb, ¹⁷⁵Lu, ¹⁷⁶Hf–Yb–Lu, ¹⁷⁷Hf, ¹⁷⁸Hf, ¹⁷⁹Hf). The total Hf signal obtained for zircons with normal Hf concentration was 1.0–2.0V. Isotopic ratios were measured using the Nu Plasma time-resolved analysis software. The isotopic ratios were later calculated off-line using an Excel spreadsheet. The raw data were filtered at 2σ and corrected for mass discrimination using an exponential law. The mass discrimination factor for Hf was determined assuming ¹⁷⁹Hf/¹⁷⁷Hf=0.7325 (Patchett *et al.*, 1981). The mass discrimination factor for Yb was determined assuming ¹⁷³Yb/¹⁷¹Yb=1.132685 (Chu *et al.*, 2002). A ¹⁷⁶Lu/¹⁷⁵Lu value of 0.02656 has been used for the correction of the ¹⁷⁶Lu interference on ¹⁷⁶Hf (Scherer *et al.*, 2001; Vervoort *et al.*, 2004). A value for the decay constant of ¹⁷⁶Lu of 1.867×10⁻¹¹a⁻¹ has been used in all calculations (Scherer *et al.*, 2001, 2007; Söderlund *et al.*, 2004).

For the calculation of ϵ_{Hf} values we use present-day chondritic ¹⁷⁶Hf/¹⁷⁷Hf=0.282785 and ¹⁷⁶Lu/¹⁷⁷Hf=0.0336 (Bouvier *et al.*, 2008). The zircon standard GJ-1 was run at frequent intervals for quality control. Multiple LA-MC-ICP-MS analyses, using the same instrumental parameters, of the reference zircon GJ-1 during the course of the present study yielded a ¹⁷⁶Hf/¹⁷⁷Hf of 0.28194±6 (1σ, n=26,

which is just within error to results obtained by solution MC-ICP-MS analyses for GJ1 (0.281998 ± 7 , Gerdes and Zeh, 2006; 0.282000 ± 5 , Morel *et al.*, 2008). Based on this result, analytical reproducibility is estimated to be in the range of ± 1.6 to 2.2 ϵ -units. The Lu-Hf isotopic data from the two samples (the Orijärvi granodiorite and the Enklinge granodiorite) are presented in Table IV.

TABLE 1. Geochemical analyses of the studied rocks

Sample	6-MJV-06	27-MJV-05	2-JP-00	5-JP-00	3-MJV-06	3-JP-00	8-JP-00	9-JP-00	10-JP-00	21-JP-00	PENK-6	PENK-51	4-MJV-06	18-JP-00
Locality	Enkinge	F. volcanics	Enkinge	Enkinge	Enkinge	Enkinge	Enkinge	Enkinge	Enkinge	Enkinge	Enkinge	Enkinge	Enkinge	Enkinge
Rocktype	F. volcanics	F. volcanics	F. dyke	Ton dyke	Tonalite	Tonalite	Tonalite	Tonalite	Pl-por.	Tonalite	Tonalite	Tonalite	Pillow lava	M. vein
Classification	F. volcanics	F. volcanics	F. dyke	F. dyke	F. plutonic	F. plutonic	F. plutonic	F. plutonic	F. plutonic	F. plutonic	F. plutonic	F. plutonic	M. volcanics	M. dyke
Laboratory	Acme	Acme	Acclabs	Acclabs	Acme	Acclabs	Acclabs	Acclabs	Acclabs	Acclabs	Genanalysis	Genanalysis	Acme	Acclabs
E-Coord*	6704542	6703465	6708853	6708912	6704663	6708869	6708957	6709153	6709224	6707410	6708873	6708661	6703736	6709866
SiO ₂ (wt.%)	69.64	76.64	77.17	68.46	76.13	71.21	73.66	74.87	70.49	70.03	75.16	72.99	49.86	62.33
TO ₂ (wt.%)	0.63	0.17	0.055	0.32	0.12	0.287	0.146	0.194	0.413	0.421	0.259	0.400	1.41	0.632
Al ₂ O ₃ (wt.%)	12.3	12.04	12.67	14.26	12.55	13.45	13.29	13.30	13.79	14.81	13.226	12.848	15.82	16.60
Fe ₂ O ₃ (wt.%)	6.92	2.05	0.93	4.32	1.88	3.94	1.77	2.42	4.15	2.89	3.002	5.004	14.04	6.51
MnO (wt.%)	0.08	0.02	0.009	0.076	0.02	0.051	0.027	0.03	0.053	0.029	n.a.	n.a.	0.24	0.127
MgO (wt.%)	0.93	0.85	0.18	1.38	0.58	1.26	0.37	0.4	0.78	0.94	0.796	1.791	5.04	1.6
CaO (wt.%)	1.45	1.24	2.55	3.83	1.02	3.35	1.15	2.14	3.5	4.05	3.358	2.659	8.49	4.4
Na ₂ O (wt.%)	3.09	3.16	4.34	3.86	4.46	3.23	3.66	3.86	3.92	3.88	3.620	3.100	3.91	3.51
K ₂ O (wt.%)	3.17	2.62	0.6	1.16	2.53	2.09	4.3	2.45	1.43	1.05	0.795	1.626	0.28	2.17
P ₂ O ₅ (wt.%)	0.12	0.02	0.01	0.06	0.03	0.05	0.04	0.05	0.09	0.09	0.041	0.060	0.15	0.39
LOI (wt.%)	1.5	1.1	0.41	0.84	0.6	0.92	0.55	0.5	0.69	0.45	n.a.	n.a.	0.7	1.82
Ba (ppm)	816.2	647.2	147	184	424	521	711	758	249	545	175	400	49.3	684
Rb (ppm)	70.5	60.8	17	45	59.9	57	114	78	50	30	20.5	70	2.7	107
Sr (ppm)	114	83.1	157	159	59	176	93	116	163	634	195	135	244	530
Ta (ppm)	0.9	1.3	0.6	0.5	0.9	0.7	1	0.7	0.6	0.3	0.5	0.68	0.2	1.1
Nb (ppm)	13.9	14.9	6	8	8.2	8	11	9	10	7	7.6	9.4	5	18
Hf (ppm)	10.3	8.6	1	3.7	5.1	3.9	3.5	4.1	4	4.3	3	4.6	3	5.4
Zr (ppm)	307	262.9	30	153	123.8	135	138	170	166	180	110	155	90	244
Y (ppm)	70.6	72.7	8	22	48.8	28	25	25	29	5	10.4	22	28.1	18
Th (ppm)	16.6	21.2	8.6	5.6	11.1	8.4	12.3	12.6	6.7	3.8	6.6	6.8	1.4	4
U (ppm)	4.9	6.3	2	1.8	3.5	3.3	4.6	4.7	2.3	1.4	2.45	2.65	0.9	2
Cr (ppm) ¹	b.d.l.	13.7	200	213	b.d.l.	211	228	223	239	191	140	155	27.4	123
Ni (ppm)	1.9	10	b.d.l.	b.d.l.	1	b.d.l.	b.d.l.	b.d.l.	b.d.l.	b.d.l.	6	11	5	b.d.l.
Pb (ppm)	1.6	2	9	7	2.2	7	11	7	5	16	10	6	5.6	11
La (ppm)	43.2	55	14.8	15.8	44.2	18.1	24	22.7	19.5	14.5	20.5	17	12.9	34.5
Ce (ppm)	93.7	110.4	25.8	30.9	90.4	36.7	45.5	45.9	39.4	22.8	37	37	30.4	74.5
Pr (ppm)	11.96	13.13	2.11	2.96	11.62	3.59	4.09	4.2	3.79	1.96	n.a.	n.a.	4.25	7.95
Nd (ppm)	46.1	52.9	8	13.4	42.3	16.3	17.5	17.6	17.3	7.9	11.4	15.5	18.7	35.2
Sm (ppm)	10.3	11.8	1.2	2.8	8.6	3.6	3.5	3.6	3.8	1.3	1.95	3.5	4.8	6
Eu (ppm)	1.77	1.12	0.36	0.61	0.45	0.6	0.44	0.56	0.79	0.98	0.6	0.8	1.4	1.71
Gd (ppm)	11.19	10.63	1	3.1	7.9	3.8	3.7	3.7	4.2	1	n.a.	n.a.	5.09	4.4
Tb (ppm)	1.91	1.98	0.2	0.5	1.34	0.7	0.6	0.6	0.7	0.2	n.a.	n.a.	0.84	0.6
Dy (ppm)	11.37	11.78	1	3.4	7.63	4.2	3.7	3.8	4.4	0.8	1.7	4.1	4.87	3.2
Ho (ppm)	2.17	2.34	0.2	0.7	1.46	0.9	0.8	0.8	0.9	0.2	n.a.	n.a.	0.95	0.6
Er (ppm)	6.51	7.4	0.7	2.2	4.11	2.8	2.4	2.5	2.8	0.5	0.94	2.3	2.49	1.5
Tm (ppm)	1.02	0.97	0.11	0.34	0.73	0.41	0.38	0.37	0.41	0.07	n.a.	n.a.	0.42	0.23
Yb (ppm)	6.58	7.23	0.8	2.4	4.45	2.7	2.7	2.5	2.8	0.5	0.94	2.2	2.47	1.4
Lu (ppm)	1.07	1.01	0.13	0.35	4.67	0.43	0.39	0.37	0.41	0.09	0.185	0.39	0.38	0.2
Eu/Eu ²	0.5	0.31	1	0.63	0.17	0.5	0.37	0.47	0.6	2.63	n.a.	n.a.	0.87	1.02

TABLE 1. (Continued)

Sample	1-MJV-06	2-MJV-06	5-MJV-06	6-JPI-00	20-JPI-00	PENK-24	PENK-33	1-JPI-00	7-JPI-00	11-JPI-00	12-JPI-00	16-JPI-00	17-JPI-00	PENK-25
Locality	Enkinge	Enkinge	Enkinge	Enkinge	Enkinge	Enkinge	Enkinge	Enkinge	Enkinge	Enkinge	Enkinge	Enkinge	Enkinge	Enkinge
Rocktype	Gabbro	Int. dyke	M. dyke	Gabbro	M. dyke	M. dyke	M. dyke	M. dyke	M. dyke	M. dyke	M. dyke	M. dyke	M. dyke	M. dyke
Classification	M. dyke	M. dyke	M. dyke	M. dyke	M. dyke	M. dyke	M. dyke	M. dyke	M. dyke	M. dyke	M. dyke	M. dyke	M. dyke	M. dyke
Laboratory	Acme	Acme	Acme	Acme	Acme	Acme	Acme	Acme	Acme	Acme	Acme	Acme	Acme	Acme
N-Coord ^a	6708829	6708584	6703736	6708924	6707412	6708748	6708834	6708821	6708940	6709315	6708906	6708938	6708938	6708672
E-Coord ^b	156286	156389	155810	157191	157566	155931	156319	157181	157188	156940	156897	161948	161752	156022
SiO ₂ (wt.%)	62.32	57.13	51.56	45.10	50.19	63.33	63.98	51.82	51.29	49.17	51.12	59.35	57.25	62.76
TiO ₂ (wt.%)	0.49	0.64	1.05	0.976	0.976	0.517	0.550	0.493	0.838	0.536	0.946	0.745	0.776	0.500
Al ₂ O ₃ (wt.%)	16.77	17.49	17.1	15.67	17.86	15.871	15.494	14.92	13.94	17.75	15.45	16.72	15.22	15.871
Fe ₂ O ₃ (wt.%)	7.36	8.91	11.91	15.08	9.45	7.149	7.006	9.63	10.61	10.84	12.24	8.76	9.61	7.006
MnO (wt.%)	0.1	0.16	0.19	0.251	0.173	n.a.	n.a.	0.192	0.174	0.238	0.19	0.135	0.163	0.163
MgO (wt.%)	1.49	2.23	4.92	6.39	4.98	2.985	3.067	6.99	7.17	5.23	5.93	2.71	4.76	3.399
CaO (wt.%)	5.44	6.69	7.49	9.44	9.38	6.296	5.597	10.23	9.98	9.56	8.74	7.16	7.35	5.737
Na ₂ O (wt.%)	3.69	3.3	4.75	0.98	3.62	3.774	3.774	2.29	2.99	3.43	2.6	3.11	2.79	3.437
K ₂ O (wt.%)	0.9	1.48	0.28	2.65	0.93	0.723	1.156	1.03	0.89	0.64	0.62	0.78	1.09	1.927
P ₂ O ₅ (wt.%)	0.14	0.1	0.09	0.12	0.26	0.069	0.078	0.02	0.11	0.08	0.15	0.12	0.12	0.069
LOI (wt.%)	1.3	1.7	0.6	1.49	0.85	n.a.	n.a.	1.33	0.93	1.02	0.74	0.49	1	n.a.
Ba (ppm)	169.2	246.7	55.3	327	237	145	240	124	144	93	106	189	173	420
Rb (ppm)	22.5	36.3	3	130	21	12	32	44	33	16	17	26	140	54
Sr (ppm)	314.6	305.7	287.5	108	624	185	190	147	168	243	221	261	220	215
Ta (ppm)	0.1	0.2	0.1	0.3	0.5	0.68	0.68	0.4	0.2	0.2	0.41	0.3	0.4	0.5
Nb (ppm)	3.7	3.3	1.7	5	9	11.6	12.5	6	3	3	7.4	5	6	9.8
Hf (ppm)	2.8	2.3	1.3	2.7	3	2.65	2.9	1.2	1.6	2.1	3.7	2.1	2.4	2.65
Zr (ppm)	84.8	64.5	40.2	99	123	84	98	39	60	78	59	87	82	90
Y (ppm)	21.1	19.6	14.2	44	25	54	43	20	24	16	30.1	14	14	14
Th (ppm)	1.1	1.1	1.3	2	1.4	4.7	4.5	1.5	1.6	2.4	1.78	2.2	1.8	3.1
U (ppm)	1.1	0.7	0.5	1	1	2.15	1.7	0.5	0.6	0.7	0.63	1	1	1.65
Cr (ppm) ^c	b.d.l.	b.d.l.	b.d.l.	98	135	170	270	150	244	75	245	137	230	200
Ni (ppm)	1.8	0.7	1.4	b.d.l.	28	21	23	b.d.l.	31	22	24	b.d.l.	30	39
Pb (ppm)	1.8	1.2	2.1	b.d.l.	13	6	4	5	5	8	9	6	6	6
La (ppm)	8.4	6.3	5.3	7.1	19.7	16.5	14.5	12.1	7.6	6.5	14.2	7.7	10.4	14
Ce (ppm)	19.8	15	12.5	17.6	46.5	42	36	16.4	15.8	15.3	31.2	15.4	21.8	37
Pr (ppm)	2.92	2.36	1.79	2.13	5.44	n.a.	n.a.	2.3	1.75	1.59	4.78	1.67	2.46	2.46
Sm (ppm)	12.3	10.6	8.1	12.2	26.9	24	17.5	10.8	9.2	8.1	22.1	8.4	12.3	22.5
Eu (ppm)	0.93	0.89	0.74	1.38	1.58	6.6	5	2.5	2.5	2.1	5.29	2.1	3	6.2
Gd (ppm)	3.29	3.09	2.35	5.6	5	8.2	6	3.1	3.3	2.2	5.74	0.85	3.1	0.96
Tb (ppm)	0.59	0.61	0.43	1.1	0.8	n.a.	n.a.	0.6	0.6	0.4	1.02	0.4	0.6	n.a.
Dy (ppm)	3.32	3	2.52	7.4	4.5	10	7	3.7	3.8	2.5	6.13	2.6	3.3	8.4
Ho (ppm)	0.69	0.69	0.48	1.6	0.8	n.a.	n.a.	0.8	0.8	0.5	1.22	0.5	0.6	n.a.
Er (ppm)	1.99	1.81	1.31	5	2.5	5.6	4.2	2.3	2.5	1.6	3.81	1.5	1.9	4.9
Tm (ppm)	0.28	0.28	0.24	0.71	0.36	n.a.	n.a.	0.32	0.35	0.26	0.553	0.21	0.29	n.a.
Yb (ppm)	1.89	1.87	1.32	4.7	2.3	4.9	4.2	2.2	2.3	1.8	3.43	1.4	1.9	4.6
Lu (ppm)	0.29	0.33	0.18	0.7	0.33	0.84	0.74	0.31	0.34	0.3	0.474	0.2	0.29	0.74
Eu/Eu ⁺ 2	0.89	0.93	1	0.9	0.93	0.43	0.57	0.97	0.85	1.05	0.7	1.16	0.91	0.45

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TABLE 1. (Continued)

Sample	PENK-32	PENK-43	PENK-45	15-JP1-00	19-JP1-00	PENK-46	PENK-47	PENK-3	PENK-37	13-JP1-00	26-MJV-05	14-JP1-00	PENK-26
Locality	Enkinge Gabbro	Enkinge Gabbro	Enkinge Gabbro	Enkinge Diorite	Enkinge Gabbro	Enkinge Gabbro	Enkinge Gabbro	Enkinge Amp. dyke	Enkinge Gabbro	Enkinge Hornbl.	Enkinge Gabbro	Enkinge Gabbro	Enkinge Gabbro
Rock type													
Classification	M. plutonic	M. plutonic	M. plutonic	M. plutonic	M. plutonic	M. plutonic	M. plutonic	Cumulate	Cumulate	Cumulate	Cumulate	Cumulate	M. plutonic
Laboratory	Genalysis	Genalysis	Genalysis	Actlabs	Actlabs	Genalysis	Genalysis	Genalysis	Genalysis	Actlabs	Acme	Actlabs	Genalysis
N-Coord*	6708799	6708699	6708594	6708982	6710627	6708342	6708360	6708897	6708354	6706947	6703410	6706987	6709023
E-Coord*	156344	156647	156689	161835	161290	167243	157260	156866	156661	161772	154232	161794	155906
SiO ₂ (wt.%)	62.73	57.14	61.57	48.14	51.91	50.87	59.04	54.11	51.19	53.84	48.40	52.67	60.97
TiO ₂ (wt.%)	0.350	0.634	0.392	0.591	0.915	3.169	1.401	0.867	0.317	0.632	0.91	0.567	0.417
Al ₂ O ₃ (wt.%)	13.982	17.005	19.272	15.70	16.60	12.470	15.116	10.959	9.825	6.47	15.48	7.49	16.249
Fe ₂ O ₃ (wt.%)	7.435	9.436	5.147	12.4	10.91	18.566	11.152	11.724	14.583	15.3	11.69	13.19	7.149
MnO (wt.%)	n.a.	n.a.	n.a.	0.201	0.18	n.a.	n.a.	n.a.	n.a.	0.276	0.19	0.251	n.a.
MgO (wt.%)	5.472	4.643	1.658	8.19	5.07	5.803	2.736	12.270	14.259	8.54	10.2	12.18	4.062
CaO (wt.%)	6.436	8.395	6.156	10.1	7.85	8.675	6.296	8.675	9.794	9.78	10.2	9.59	7.276
Na ₂ O (wt.%)	3.235	3.033	6.066	1.38	2.67	1.685	3.168	1.820	1.321	0.73	1.91	1.05	3.774
K ₂ O (wt.%)	1.060	0.590	0.169	1.11	2.06	0.518	1.988	0.675	0.120	0.29	1.24	0.47	0.771
P ₂ O ₅ (wt.%)	0.041	0.073	0.082	0.03	0.13	0.087	0.220	0.078	0.046	0.06	0.12	0.06	0.046
LOI (wt.%)	n.a.	n.a.	n.a.	1.42	1.31	n.a.	n.a.	n.a.	n.a.	1.08	1.1	1.5	n.a.
Ba (ppm)	220	112	210	99	357	72	360	62	24	31	71	105	135
Rb (ppm)	30	14.5	4	69	79	10.8	68	26.5	0.7	8	66.1	34	15
Sr (ppm)	165	200	290	182	302	90	205	140	19.5	33	207.2	47	190
Ta (ppm)	0.33	0.33	0.48	0.11	0.4	0.54	0.84	0.21	0.32	0.12	0.2	0.2	0.38
Nb (ppm)	6.6	5.6	8.4	3.4	6	8.4	13	3.4	5	3.3	2.4	2	5.8
Hf (ppm)	2	1.9	2.45	0.9	1.5	2.15	3.4	1.45	1.6	1.2	1.5	1	1.6
Zr (ppm)	66	56	92	40	46	66	118	46	66	41	44.8	47	45
Y (ppm)	19	18	21.5	8.3	15	35	40	15	15	14.9	20.1	13	11.2
Th (ppm)	2.2	2.55	3.7	0.7	1.2	1.45	7.4	0.56	1.8	2.08	1.2	0.9	2.4
U (ppm)	1.08	0.96	1.6	0.37	0.8	0.64	2.75	0.45	1.35	0.65	0.4	0.4	1.14
Cr (ppm) [†]	260	104	108	185	172	106	92	1120	1200	391	307.9	475	125
Ni (ppm)	56	20	8	24	29	15	1	195	190	40	132	82	17
Pb (ppm)	4	4	12	b.d.l.	7	n.a.	n.a.	6	4	b.d.l.	2.3	b.d.l.	4
La (ppm)	12	9.4	14.5	3.6	7.7	7.8	22.5	3.5	4.6	3.54	7.1	4.6	11.4
Ce (ppm)	29	22.5	30	7.83	16.9	20	48	10	13.5	8.3	12.7	10.2	23
Pr (ppm)	n.a.	n.a.	n.a.	1.09	1.87	n.a.	n.a.	n.a.	n.a.	1.26	1.75	1.1	n.a.
Nd (ppm)	13	10	12.5	4.97	9.2	12	23.5	7.4	8.4	6.3	8.7	5.9	7.4
Sm (ppm)	2.85	2.5	2.85	1.29	2.2	3.7	5.4	2.3	2.2	1.76	2.5	1.6	1.65
Eu (ppm)	0.9	0.8	0.82	0.524	0.93	1.25	1.75	0.84	1.14	0.513	0.83	0.5	0.7
Gd (ppm)	3.1	2.9	3.2	1.52	2.4	4.7	6.4	2.55	2.4	2.19	2.94	2.1	1.8
Tb (ppm)	n.a.	n.a.	n.a.	0.29	0.4	n.a.	n.a.	n.a.	n.a.	0.44	0.58	0.4	n.a.
Dy (ppm)	3.4	3.3	3.7	1.78	2.5	6.4	7.2	2.65	2.5	2.7	3.58	2.2	2
Ho (ppm)	n.a.	n.a.	n.a.	0.37	0.5	n.a.	n.a.	n.a.	n.a.	0.56	0.73	0.5	n.a.
Er (ppm)	1.95	1.9	2.1	1.12	1.5	3.8	3.9	1.4	1.45	1.64	2.36	1.3	1.2
Tm (ppm)	n.a.	n.a.	n.a.	0.165	0.22	n.a.	n.a.	n.a.	n.a.	0.244	0.27	0.19	n.a.
Yb (ppm)	2.05	1.75	1.9	1.06	1.5	3.6	3.5	1.25	1.3	1.54	1.85	1.2	1.12
Lu (ppm)	0.36	0.31	0.33	0.153	0.24	0.6	0.6	0.215	0.24	0.22	0.3	0.17	0.195
Eu/Eu ²	0.93	0.91	0.83	1.14	1.24	0.92	0.91	1.06	1.52	0.8	0.94	0.83	1.24

TABLE 1. (Continued)

Sample	46.2-MAV-02	101-MAV-02	22-MUV-06	45-MAV-02	TK-13-10-4	12.2-MAV-02	11-MAV-02	50-MAV-02	30-MUV-06	33-MUV-06	29a-MUV-06	37.2-MAV-02	68-MAV-02
Locality	Orilävi	Orilävi	Orilävi	Orilävi	Arnth	Orilävi	Orilävi	Orilävi	Orilävi	Orilävi	Orilävi	Orilävi	Orilävi
Rocktype	UM. rock	Gabbro	Gabbro	Gabbro		Tonalite	Tonalite		Tonalite	Tonalite	Tonalite		Tonalite
Classification	Lay. intr.	Lay. intr.	Lay. intr.	Lay. intr.	Lay. intr.	F. plutonic	F. plutonic	F. plutonic	F. plutonic	F. plutonic	F. plutonic	F. plutonic	F. plutonic
Laboratory	Acme	Acme	Acme	Acme	Acme	Acme	Acme	Acme	Acme	Acme	Acme	Acme	Acme
N-Coord*	6676911	6676933	6676944	6676936	6676984	6673082	6675331	6677231	6673403	6674647	6673955	6671660	6674174
E-Coord*	302029	301696	302002	302159	302032	286694	284740	306119	302079	301158	296673	300329	299848
SiO ₂ (wt.%)	38.79	43.79	45.14	43.31	54.10	77.85	71.44	67.77	70.69	68.30	73.48	71.34	68.19
TiO ₂ (wt.%)	3.21	2.15	4.45	2.97	0.75	0.2	0.34	0.51	0.29	0.30	0.18	0.37	0.31
Al ₂ O ₃ (wt.%)	14.01	16.94	13.85	15.06	25.05	11.93	13.93	14.79	14.05	14.55	13.1	14.09	14.42
Fe ₂ O ₃ (wt.%)	26.3	14.95	16.23	20.3	2.57	2.14	4.09	4.08	4.36	5.15	2.89	3.17	5.23
MnO (wt.%)	0.43	0.18	0.25	0.33	0.05	0.03	0.07	0.05	0.07	0.08	0.03	0.04	0.08
MgO (wt.%)	7.63	6.71	6.13	44.7	0.77	0.28	0.75	1.98	0.86	1.18	0.44	0.62	1.35
CaO (wt.%)	6.91	11.96	9.87	90.7	9.09	1.83	2.83	4.39	3.06	3.87	2.25	2.26	3.97
Na ₂ O (wt.%)	1.51	1.58	2.36	2.7	5.47	4.74	2.8	3.59	3.61	3.24	3.84	3.6	3.5
K ₂ O (wt.%)	0.28	0.36	0.52	0.23	0.79	0.24	2.74	1.29	2.04	1.98	1.48	3.63	1.91
P ₂ O ₅ (wt.%)	0.19	0.13	0.15	1.51	0.28	0.01	0.05	0.15	0.07	0.06	0.05	0.06	0.07
LOI (wt.%)	n.a.	n.a.	0.9	na	na	na.	na.	na.	0.9	1.1	2.1	n.a.	n.a.
Ba (ppm)	87	75	118.4	114	174	155	863	568	725.4	414.4	624.2	1160	638
Rb (ppm)	8.1	6.3	9.1	4	11.5	7.7	65.2	31.2	53.7	53.1	31.3	81.7	58.3
Sr (ppm)	107.3	359.2	353.1	520.7	782.3	133.8	250.6	851.1	163.3	156.6	143.2	321.2	184.4
Ta (ppm)	0.1	0.1	0.3	0.2	0.2	0.8	0.7	0.4	0.8	0.6	0.7	0.8	0.5
Nb (ppm)	1.7	0.7	2.9	2.2	2.9	12.1	10	6.3	8.3	6	7	8.4	6.7
Hf (ppm)	0.6	0.5	1.2	0.8	b.d.l.	6.1	4.5	3	4.2	3.6	4.1	4.2	3.2
Zr (ppm)	18.2	15	28.6	27.8	17.4	191.5	150.4	99.5	134.8	114.6	110.3	154.5	105.7
Y (ppm)	7	10.7	11.6	28.8	8.5	31.9	26.4	5.1	23.3	22	15	14.1	17.7
Th (ppm)	0.3	0.2	2.1	1	0.7	11.9	10.6	4.3	7.8	7.3	14.8	10.3	12
U (ppm)	0.2	0.1	0.6	0.3	0.3	4.3	5.9	1.8	4.6	2.7	4.3	3	2.4
Cr (ppm) [†]	6.84	88.95	b.d.l.	7	n.a.	7	34.21	41.05	b.d.l.	b.d.l.	b.d.l.	34.21	7
Ni (ppm)	0.1	36.6	11.7	0.1	n.a.	1.7	2.2	14.2	1	4.7	1	1.9	1.7
Pb (ppm)	0.7	2.4	259	0.6	n.a.	35.1	110.8	9.7	4.2	7.2	5.6	15.9	4
La (ppm)	3.2	2.9	5.7	10.4	7	33.8	27.5	21.1	18.6	27.9	24.6	38	24.2
Ce (ppm)	7.9	7.4	12.8	26.2	15.5	68.8	56.3	40.2	36.3	55.5	44.5	69.5	46.6
Pr (ppm)	1.08	1.07	1.89	4.19	1.79	7.65	6.38	4.36	4.09	6.04	4.56	7.35	5.08
Nd (ppm)	5.2	5.3	7.9	23.8	8.2	29.6	25.9	17.6	17.6	21.4	17	25.6	17.9
Sm (ppm)	1.2	1.5	1.9	6.3	2	5.2	5.2	2.4	3.5	4	2.5	3.9	3.4
Eu (ppm)	1.14	0.84	0.93	2.95	2.15	0.91	0.95	0.73	0.63	0.55	0.55	1.03	0.76
Gd (ppm)	1.3	2.08	2.28	6.94	1.75	5.18	3.98	1.58	3.74	3.7	2.18	2.88	2.78
Tb (ppm)	0.2	0.35	0.35	1.05	0.27	0.84	0.71	0.21	0.69	0.7	0.43	0.46	0.46
Dy (ppm)	1.36	1.89	2.31	5.93	1.64	5.22	4.07	1.07	3.75	3.89	2.29	2.5	2.67
Ho (ppm)	0.25	0.4	0.41	1.03	0.3	3.25	0.88	0.17	0.75	2.12	1.47	0.46	0.56
Er (ppm)	0.65	1.03	1.11	2.59	0.82	3.25	2.78	0.46	2.2	2.12	1.47	1.31	1.7
Tm (ppm)	0.09	0.16	0.17	0.33	0.08	0.49	0.41	0.06	0.36	0.32	0.22	0.19	0.28
Yb (ppm)	0.62	0.89	0.94	1.82	0.61	3.26	2.92	0.5	2.05	2	1.72	1.44	1.79
Lu (ppm)	0.08	0.12	0.16	0.24	0.08	0.51	0.35	0.06	0.31	0.33	0.24	0.19	0.31
Eu/Eu ⁺ *	2.79	1.45	1.37	1.36	3.51	0.54	0.64	1.15	0.53	0.44	0.72	0.94	0.76

TABLE 1. (Continued)

Sample	58-MAV-02	64-MAV-02	23-MUV-06	27-MUV-06	2-MAV-02	32.2-MUV-06	12.1-MAV-02	49-MUV-07	31-MAV-06	86-MAV-02	53-MAV-02	34-MAV-02	65-MAV-02
Locality	Orilävi	Orilävi	Orilävi	Orilävi	Orilävi	Orilävi	Orilävi	Orilävi	Orilävi	Orilävi	Orilävi	Orilävi	Orilävi
Rocktype	Tonalite	Oz por.	Rhyolite	Tonalite	Tonalite	Int. dyke	Diorite	Diorite	Diorite	Diorite	Diorite	M. plutonic	Gabbro
Classification	F. plutonic	F. plutonic	F. volcanics	F. plutonic	F. plutonic	M. dyke	M. plutonic	M. plutonic	M. plutonic	M. plutonic	M. plutonic	M. plutonic	M. plutonic
Laboratory	Acme	Acme	Acme	Acme	Acme	Acme	Acme	Acme	Acme	Acme	Acme	Acme	Acme
N-Coord ^a	6679435	6677900	6681303	6673554	6675251	6673778	6673082	6679712	6677166	6675357	6679623	6672373	6671810
E-Coord ^b	309335	300116	306149	288840	291339	306210	288694	306540	306067	308145	304540	303684	295895
SiO ₂ (wt.%)	67.15	72.96	83.55	70.32	71.50	61.13	68.75	56.42	61.36	54.21	55.06	50.70	45.76
TiO ₂ (wt.%)	0.35	0.17	0.13	0.35	0.32	0.87	0.51	1.13	0.69	1.35	0.70	1.21	0.24
Al ₂ O ₃ (wt.%)	14.57	12.63	8.13	14.00	13.32	16.66	15.12	14.1	16.72	15.81	14.94	16.05	14.89
Fe ₂ O ₃ (wt.%)	5.94	2.07	1.29	4.41	3.82	6.47	8.88	10.15	5.65	10.94	9.28	9.82	12.23
MnO (wt.%)	0.1	0.02	0.02	0.06	0.05	0.08	0.17	0.15	0.07	0.14	0.14	0.14	0.18
MgO (wt.%)	1.74	0.93	0.41	103	0.72	3.02	4.06	4.39	3.14	3.72	5.78	6.46	10.83
CaO (wt.%)	3.43	0.89	3.82	342	2.47	5.92	7.35	7.11	5.84	7.37	8.93	10.48	12.92
Na ₂ O (wt.%)	3.46	1.44	0.81	3.38	3.31	3.39	2.1	3.23	3.54	3.41	2.57	2.72	0.92
K ₂ O (wt.%)	1.4	7.7	0.38	1.6	3.4	1.3	1.3	1.77	1.23	1.42	1.11	1.06	0.23
P ₂ O ₅ (wt.%)	0.05	0.02	0.04	0.09	0.06	0.27	0.15	0.235	0.22	0.35	0.11	0.37	0.03
LOI (wt.%)	n.a.	n.a.	1.3	1.3	n.a.	0.8	n.a.	1.1	1.4	n.a.	n.a.	n.a.	n.a.
Ba (ppm)	453	1437	456	586	923	414.9	398	443	518.6	828	496	506	28
Rb (ppm)	34.4	91	10.4	42.8	74	28.6	38.3	49.9	25.6	30.8	26.8	15.1	6.9
Sr (ppm)	171	32.4	73.3	286.3	247.8	796.7	294.6	358.3	894.4	472.3	205.7	621.3	155.4
Ta (ppm)	0.5	0.7	0.5	0.9	0.6	0.6	0.6	0.8	0.5	0.6	0.4	0.6	0.1
Nb (ppm)	6.8	5.8	5.3	8.8	8.8	8.2	9.4	16.8	6.5	12.9	6.1	11.5	0.8
Hf (ppm)	3.8	3	3	5.5	4.5	6.1	2.3	3.4	3.3	4.2	2.5	2.9	0.5
Zr (ppm)	113.5	84.2	101	159	143.6	209.8	70	117.5	6	160.8	80.7	107.6	10.1
Y (ppm)	20.3	11.3	12.9	20.6	22.7	8.2	17.5	27.5	26.3	26.3	24.6	20.3	7.7
Th (ppm)	7.4	11.3	9.9	8	11.5	6.7	6.3	6.5	7	2.4	3.1	2.4	0.7
U (ppm)	2.6	3.2	4	4.3	2.3	1.8	2.6	2.1	1.5	0.9	1.4	1.2	0.4
Cr (ppm) ^c	13.68	13.68	13.7	b.d.l.	34.21	13.7	41.05	88.9	41.1	5.7	191.58	164.21	171.05
Ni (ppm)	3.5	1.2	2.2	3.5	4.1	16.4	13.6	27.5	24.5	5.7	36.2	37.5	19.9
Pb (ppm)	7.5	6.8	10.9	4.1	2.8	3	8.7	4.8	3.2	4.3	2	12.6	3
La (ppm)	24.5	20.8	18.9	21.7	15.8	28.6	17.3	26.4	35.5	26.1	13.8	25.9	3.2
Ce (ppm)	46	36	38.4	44.3	33.6	37.6	37.6	56.6	68.2	63.5	29.1	56.8	8.2
Pr (ppm)	5.65	3.72	4.34	5.1	4.13	6.42	4.67	7.63	6.52	7.87	3.37	6.88	1.2
Nd (ppm)	22.8	13.5	14.1	21	18	25	20.1	29.5	22.9	30	15.5	27.5	5.7
Sm (ppm)	4	2.3	2.4	3.9	4.2	3.4	4	5.59	2.8	5.6	3	4.8	1.6
Eu (ppm)	0.83	0.33	0.58	0.76	0.89	0.93	1.02	1.19	0.8	1.54	0.81	1.39	0.44
Gd (ppm)	3.21	1.54	2.07	3.57	3.7	2.71	3.61	5.12	1.76	4.94	3.5	3.9	1.45
Tb (ppm)	0.59	0.28	0.63	0.37	0.58	0.37	0.5	5.12	0.26	0.72	0.64	0.62	0.25
Dy (ppm)	3.46	1.68	1.98	3.13	3.62	1.48	3.05	5.15	1.14	4.4	3.99	3.74	1.43
Ho (ppm)	0.67	0.33	0.31	0.62	0.71	0.28	0.58	1	0.16	0.87	0.82	0.74	0.28
Er (ppm)	2.09	1.14	1.05	1.96	2.33	0.75	1.74	2.83	0.51	2.45	2.56	2	0.82
Tm (ppm)	0.34	0.19	0.21	0.32	0.34	0.11	0.26	0.45	0.08	0.41	0.39	0.31	0.11
Yb (ppm)	2.1	1.36	1.35	2.07	2.46	0.75	1.78	2.65	0.51	2.49	2.63	1.78	0.73
Lu (ppm)	0.29	0.2	0.21	0.3	0.37	0.1	0.27	0.42	0.07	0.37	0.38	0.29	0.1
Eu/Eu ²⁺	0.71	0.54	0.8	0.62	0.69	0.94	0.82	0.68	1.1	0.9	0.76	0.98	0.88

TABLE 1. (Continued)

Sample	57-MAV-02	28-MUV-06	37.1-MAV-02	24-MUV-06	35.2-MUV-06	34-MUV-06
Locality	Orijävi	Orijävi	Orijävi	Orijävi	Orijävi	Orijävi
Rocktype	Tonalite	Tonalite	Tonalite	Basalt	M. dyke	Int. dyke
Classification	F. plutonic	F. plutonic	F. plutonic	M. volcanics	M. dyke	M. dyke
Laboratory	Acme	Acme	Acme	Acme	Acme	Acme
N-Coord*	6678805	6672386	6671660	6681109	6679309	6672715
E-Coord*	311739	295841	300329	306080	312230	296591
SiO ₂ (wt.%)	69.85	65.74	65.00	51.52	46.80	59.57
TiO ₂ (wt.%)	0.33	0.53	0.65	0.56	0.77	0.69
Al ₂ O ₃ (wt.%)	13.36	14.49	15.85	16.84	16.69	16.16
Fe ₂ O ₃ (wt.%)	5.38	7.78	5.61	10.04	10.74	9.42
MnO (wt.%)	0.08	0.11	0.09	0.14	0.2	0.15
MgO (wt.%)	2.18	1.4	1.45	7.32	8.23	1.84
CaO (wt.%)	1.91	5.19	4.49	7.73	11.85	6.26
Na ₂ O (wt.%)	3.59	3.01	3.99	3.28	2.3	3.58
K ₂ O (wt.%)	2.19	0.65	1.89	0.58	0.9	0.94
P ₂ O ₅ (wt.%)	0.07	0.16	0.18	0.09	0.26	0.21
LOI (wt.%)	n.a.	0.9	n.a.	1.7	1	1
Ba (ppm)	452	272.2	1008	155.1	102.3	276.8
Rb (ppm)	117.2	16.5	61.6	11.8	11.3	23.1
Sr (ppm)	132.8	240.6	580.9	156.1	418.9	372
Ta (ppm)	0.4	0.4	0.6	0.3	0.3	0.3
Nb (ppm)	7	6.5	12.3	3.6	5.2	3.6
Hf (ppm)	4.4	5.8	5.9	2.1	2.2	2.3
Zr (ppm)	134.8	172.5	231.6	56.4	65.2	63.4
Y (ppm)	22.7	26.4	19.7	22.2	19.8	20.9
Th (ppm)	5.6	5.4	4.2	3.6	5.5	2.2
U (ppm)	2.4	2.6	2.6	1.3	2	1.1
Cr (ppm) [†]	13.68	b.d.l.	7	17.1	164.2	b.d.l.
Ni (ppm)	1.4	2.5	4.2	11.2	36	1.9
Pb (ppm)	14.1	1.1	3.2	11.6	4	3.4
La (ppm)	18.3	25.2	33.9	14	24	3.8
Ce (ppm)	39.1	52.2	65.5	29.7	55.2	16.2
Pr (ppm)	4.7	6.61	7.42	3.9	6.91	1.98
Nd (ppm)	20.4	25.7	30.5	15.3	29.8	11.5
Sm (ppm)	3.9	4.8	5.3	3.6	5.7	3.3
Eu (ppm)	0.97	1.23	1.35	1.21	1.52	1.11
Gd (ppm)	3.44	4.69	4.45	3.77	4.5	3.56
Tb (ppm)	0.61	0.83	0.63	0.62	0.67	0.66
Dy (ppm)	3.91	4.02	3.74	3.26	3.46	3.48
Ho (ppm)	0.7	0.86	0.63	0.63	0.65	0.75
Er (ppm)	2.44	2.46	1.9	1.92	1.81	2.19
Tm (ppm)	0.32	0.41	0.27	0.3	0.24	0.3
Yb (ppm)	2.36	2.37	1.94	1.84	1.48	1.95
Lu (ppm)	0.32	0.39	0.27	0.3	0.23	0.31
Eu/Eu ²⁺	0.81	0.79	0.85	1	0.92	0.99

*Coordinates in EUREF-FIN system. 1) Calculated after Cr₂O₃. 2) Normalizing values after Boynton (1984).
b.d.l.=below detection limit; n.a.=not analysed; F=Feisic, Int=Intermediate, M=Mafic, UM=Ultra mafic.
Ton=Tonalite, Pl=por=Plagioclase porphyrite, Gab=Gabbro, Anorth=Anorthosite, Lay intr=L-layered intrusion,
Grd=Granodiorite, Qz=por=Quartz porphyry, Hornb=Hornblende.

TABLE II. Zircon U-Pb isotope data for the Orijärvi and Enklinge granodiorites

Sample	ppm		²⁰⁶ Pbc (%)	Ratios*				p*	Discordance central (%)	Ages				Comment					
	U	Th		Pb	²⁰⁷ Pb/ ²⁰⁶ Pb	1σ	²⁰⁷ Pb/ ²³⁵ U			1σ	²⁰⁷ Pb/ ²⁰⁶ Pb	1σ	²⁰⁷ Pb/ ²³⁵ U		1σ	²⁰⁶ Pb/ ²³⁸ U	1σ		
Orijarvi granodiorite (29a-MJV-06) ¹																			
Orijarno-38	202	46	71	0.01	0.11550	0.00052	5.43080	0.11097	0.34102	0.00689	0.99	0	1888	8	1890	17	1892	33	igneous
Orijarno-42	168	36	59	0.01	0.11527	0.00055	5.45769	0.11183	0.34341	0.00694	0.98	1	1884	9	1894	17	1903	33	igneous
Orijarno-44	264	62	94	0.01	0.11544	0.00049	5.45642	0.11127	0.34282	0.00692	0.99	1	1887	8	1894	17	1900	33	igneous
Orijarno-49	191	38	68	0.01	0.11505	0.00054	5.47274	0.11199	0.34501	0.00697	0.98	2	1881	8	1896	17	1911	33	igneous
Orijarno-8	646	173	237	0.00	0.11558	0.00053	5.67099	0.11597	0.35586	0.00719	0.99	4	1889	8	1927	18	1963	34	igneous
Orijarno-9	200	56	71	0.01	0.11648	0.00057	5.41303	0.11102	0.33705	0.00681	0.98	-2	1903	9	1887	17	1872	33	igneous
Orijarno-1	516	130	186	0.00	0.11642	0.00045	5.61536	0.11464	0.34983	0.00710	0.99	2	1902	7	1918	17	1934	34	igneous
Orijarno-15	414	93	145	0.01	0.11582	0.00048	5.46810	0.11194	0.34241	0.00696	0.99	0	1883	7	1896	17	1898	33	igneous
Orijarno-14	497	125	161	0.00	0.11604	0.00055	5.26107	0.10826	0.32882	0.00669	0.98	-3	1886	8	1863	17	1833	32	igneous
Orijarno-22	329	68	103	0.01	0.11455	0.00054	5.04970	0.10387	0.31971	0.00650	0.98	-5	1873	8	1828	17	1788	32	igneous
Orijarno-64	271	79	90	0.01	0.11586	0.00050	5.14753	0.10549	0.32222	0.00655	0.99	-5	1893	8	1844	17	1801	32	igneous
Orijarno-46	400	91	123	0.01	0.11336	0.00044	4.54882	0.09284	0.29102	0.00591	0.99	-11	1854	7	1740	17	1647	29	igneous
Enklinge granodiorite (3-MJV-06) ^{2,3}																			
3-MJV-06-60a	209	-	73	0.16	0.11017	0.00057	5.25884	0.26359	0.34620	0.01726	1.00	7	1802	9	1862	43	1916	83	metamorphic
3-MJV-06-60b	461	-	133	0.10	0.11064	0.00060	4.46766	0.22396	0.29286	0.01460	0.99	-10	1810	9	1725	42	1656	73	metamorphic
3-MJV-06-48	371	-	55	0.00	0.11115	0.00065	2.36621	0.11049	0.15439	0.00715	0.99	-53	1818	10	1232	33	926	40	metamorphic
3-MJV-06-10a	312	-	60	0.26	0.11184	0.00060	3.03148	0.13638	0.19659	0.00878	0.99	-40	1830	10	1416	34	1157	47	metamorphic
3-MJV-06-28	219	-	68	0.06	0.11225	0.00059	4.87619	0.11972	0.31506	0.00755	0.98	-4	1836	9	1798	21	1766	37	metamorphic
3-MJV-06-20	256	-	86	0.14	0.11241	0.00055	5.13501	0.25630	0.33130	0.01645	1.00	0	1839	9	1842	42	1845	80	metamorphic
3-MJV-06-10b	236	-	62	0.00	0.11266	0.00056	4.11216	0.18544	0.26473	0.01187	0.99	-20	1843	8	1657	37	1514	60	metamorphic
3-MJV-06-121a	588	-	190	0.11	0.11283	0.00056	5.13083	0.23942	0.32980	0.01530	0.99	-1	1846	9	1841	40	1837	74	metamorphic
3-MJV-06-9a	347	-	121	0.02	0.11296	0.00084	5.37979	0.18983	0.34541	0.01192	0.98	4	1848	13	1882	30	1913	57	metamorphic
3-MJV-06-78	314	-	95	0.38	0.11296	0.00073	4.70238	0.25821	0.30192	0.01646	0.99	-9	1848	11	1768	46	1701	82	metamorphic
3-MJV-06-90b	687	-	221	0.49	0.11352	0.00061	5.23407	0.21793	0.33440	0.01381	0.99	0	1856	9	1858	35	1860	67	metamorphic
3-MJV-06-21	262	-	168	0.10	0.11366	0.00053	4.79558	0.23525	0.30599	0.01494	1.00	-8	1859	8	1784	41	1721	74	metamorphic
3-MJV-06-59a	331	-	85	0.23	0.11370	0.00056	5.82061	0.26799	0.37128	0.01699	0.99	11	1859	9	1949	40	2035	80	metamorphic
3-MJV-06-3	468	-	123	0.12	0.11346	0.00060	5.73436	0.26604	0.36657	0.01689	0.99	10	1856	9	1937	40	2013	80	metamorphic
3-MJV-06-152	524	-	101	0.01	0.11461	0.00054	3.66326	0.14286	0.23181	0.00897	0.99	-31	1874	8	1563	31	1344	47	igneous
3-MJV-06-9b	285	-	113	0.00	0.11445	0.00058	5.43922	0.25762	0.34469	0.01623	0.99	2	1871	9	1891	41	1909	78	igneous
3-MJV-06-18	458	-	115	0.06	0.11466	0.00055	5.47107	0.24298	0.34606	0.01528	0.99	3	1875	8	1866	38	1916	73	igneous
3-MJV-06-35	367	-	161	0.03	0.11467	0.00055	5.28988	0.14505	0.33517	0.00903	0.98	-1	1875	8	1869	23	1863	44	igneous
3-MJV-06-36	1072	-	121	0.06	0.11497	0.00055	5.64585	0.14742	0.36616	0.00914	0.98	5	1879	8	1923	23	1964	43	igneous
3-MJV-06-37	374	-	77	0.07	0.11489	0.00063	5.68591	0.29411	0.35894	0.01846	0.99	6	1878	10	1929	45	1977	88	igneous
3-MJV-06-61	380	-	282	0.07	0.11539	0.00057	5.61169	0.25322	0.36272	0.01582	0.99	4	1886	8	1918	39	1948	75	igneous
3-MJV-06-121b	717	-	135	0.00	0.11497	0.00054	5.50026	0.20479	0.36688	0.01282	0.99	3	1879	8	1901	32	1920	61	igneous
3-MJV-06-195	1049	-	376	0.00	0.11566	0.00061	5.70335	0.19479	0.35763	0.01207	0.99	5	1890	9	1932	30	1971	57	igneous
3-MJV-06-181	90	-	235	0.00	0.11644	0.00061	5.49400	0.20018	0.34221	0.01234	0.99	0	1902	9	1900	31	1897	59	igneous
3-MJV-06-29b	367	-	137	0.26	0.11526	0.00061	5.93969	0.25812	0.37376	0.01612	0.99	10	1884	9	1967	38	2047	76	igneous
3-MJV-06-81	221	-	133	0.07	0.11568	0.00065	6.07912	0.24831	0.38115	0.01542	0.99	12	1890	10	1987	36	2082	72	igneous
3-MJV-06-45	210	-	350	0.01	0.11474	0.00056	5.99992	0.17144	0.37925	0.01068	0.99	12	1876	8	1976	25	2073	50	igneous
3-MJV-06-46	770	-	80	0.14	0.11482	0.00056	5.99935	0.22464	0.37897	0.01407	0.99	12	1877	9	1976	33	2071	66	igneous
3-MJV-06-59b	304	-	29	0.00	0.11461	0.00060	6.06966	0.25660	0.38410	0.01611	0.99	14	1874	9	1986	37	2095	75	igneous
3-MJV-06-65b	296	-	114	0.00	0.11967	0.00103	6.39431	0.30575	0.38752	0.01823	0.98	10	1951	15	2031	42	2111	85	inherited

TABLE II. (Continued)

Sample	ppm			$^{206}\text{Pb}/\text{Pb}^*$ (%)	Ratios*						ρ^*	Discordance central (%)	Ages						Comment
	U	Th	Pb		$^{207}\text{Pb}/^{206}\text{Pb}^*$	1 σ	$^{207}\text{Pb}/^{235}\text{U}^*$	1 σ	$^{206}\text{Pb}/^{238}\text{U}^*$	1 σ			$^{207}\text{Pb}/^{206}\text{Pb}$	1 σ	$^{207}\text{Pb}/^{235}\text{U}$	1 σ	$^{206}\text{Pb}/^{238}\text{U}$	1 σ	
3-M/V-06-106	559	-	127	0.00	0.11975	0.00140	4.17742	0.19116	0.25300	0.01119	0.97	-29	1953	20	1670	37	1454	58	Inherited
3-M/V-06-4	352	-	90	0.00	0.11977	0.00078	4.10897	0.20904	0.24883	0.01256	0.99	-30	1953	11	1656	42	1432	65	Inherited
3-M/V-06-90	324	-	98	0.00	0.12172	0.00094	5.27486	0.22521	0.31430	0.01320	0.98	-13	1982	13	1865	36	1762	65	Inherited
3-M/V-06-38	248	-	70	0.00	0.12194	0.00079	4.71069	0.22737	0.28018	0.01340	0.99	-22	1985	12	1769	40	1592	67	Inherited
3-M/V-06-65a	496	-	183	0.00	0.12207	0.00139	6.49231	0.24482	0.38573	0.01387	0.95	7	1987	19	2045	33	2103	65	Inherited
3-M/V-06-39b	323	-	120	0.00	0.12285	0.00082	6.30050	0.28779	0.37195	0.01681	0.99	2	1998	12	2019	40	2039	79	Inherited
3-M/V-06-90c	318	-	89	0.00	0.12644	0.00097	5.02026	0.21927	0.28796	0.01238	0.99	-23	2049	13	1823	37	1631	62	Inherited
3-M/V-06-101	324	-	104	0.00	0.12726	0.00085	5.89586	0.24865	0.33601	0.01399	0.99	-11	2060	12	1961	37	1867	68	Inherited
3-M/V-06-19	178	-	32	0.00	0.13051	0.00156	3.25458	0.19802	0.18086	0.01079	0.98	-53	2105	20	1470	47	1072	59	Inherited
3-M/V-06-47	437	-	166	0.00	0.13331	0.00186	7.10770	0.26888	0.38668	0.01359	0.93	-2	2142	24	2125	34	2107	63	Inherited
3-M/V-06-52	379	-	128	0.00	0.13468	0.00127	6.41676	0.26599	0.34555	0.01385	0.97	-13	2160	16	2035	36	1913	67	Inherited
3-M/V-06-39a	202	-	56	0.00	0.14159	0.00141	5.50812	0.24112	0.28215	0.01203	0.97	-32	2247	17	1902	38	1602	60	Inherited

* Errors are 1-sigma absolute; ρ =Error correlation between $^{206}\text{Pb}/^{238}\text{U}$ and $^{207}\text{Pb}/^{235}\text{U}$, normal discordance are showed by negative number.
1) The Onjavi granulorite U–Pb dating analyses were performed using a Nu Plasma Atom single collector ICP-MS with Photon Machine Excite laser ablation system.
2) The Enklinge granulorite U–Pb dating analyses were performed using a Nu Plasma HR multicollector ICP-MS with Photon Machine Analyte G2 laser microprobe.
3) Tom Andersen is greatly acknowledged for providing the program used for data reduction of the Enklinge granulorite.

TABLE III. Sm-Nd isotope data from Orijärvi and Enklinge

Sample	Rock type	Locality	Sm (ppm) ¹	Nd (ppm) ¹	¹⁴⁷ Sm/ ¹⁴⁴ Nd ¹	¹⁴³ Nd/ ¹⁴⁴ Nd ± 2σ _m ² (measured)	ε _{Nd} ³ (present)	ε _{Nd} ³ (initial)	T _{CHUR} ⁴ (Ga)	T _{DM} ⁵ (Ga)
22-MJV-06	Gabbro	Orijärvi	1.83	6.09	0.1818	0.512554 ± 12	-1.6	+2.0 (1892)	0.87	2.35
23-MJV-06	Rhyolite	Orijärvi	2.16	11.9	0.1099	0.511537 ± 11	-21.5	-0.4 (1892)	1.93	2.21
29a-MJV-06	Granodiorite	Orijärvi	2.86	16.3	0.1052	0.511506 ± 10	-22.1	+0.1 (1892)	1.87	2.15
36-MJV-06	Basalt	Orijärvi	13.6	62.1	0.1323	0.511890 ± 2	-14.6	+1.1 (1892)	1.77	2.15
1-MJV-06	Gabbro dyke	Enklinge	3.14	12.0	0.1588	0.512267 ± 15	-7.2	+1.9 (1882)	1.49	2.15
3-MJV-06	Granodiorite	Enklinge	7.43	35.5	0.1264	0.511825 ± 13	-15.9	+1.1 (1882)	1.76	2.12
4-MJV-06	Basalt	Enklinge	4.21	16.3	0.1560	0.512233 ± 15	-7.9	+1.9 (1882)	1.52	2.13
5-MJV-06	Basalt dyke	Enklinge	1.82	7.24	0.1521	0.512233 ± 33	-7.9	+2.9 (1882)	1.39	2.00
6-MJV-06	Rhyolite	Enklinge	9.84	43.5	0.1367	0.511958 ± 16	-13.3	+1.2 (1882)	1.73	2.14
BCR-2	Basalt standard	Columbia river	6.65	28.9	0.1391	0.512624 ± 3	-0.3		0.04	0.87

1) Sm and Nd contents and ¹⁴⁷Sm/¹⁴⁴Nd ratio from isotope dilution analysis with combined ¹⁴⁷Sm-¹⁵⁰Nd tracer. Estimated analytical uncertainty of ¹⁴⁷Sm/¹⁴⁴Nd ratio is ±0.5 %.

2) ¹⁴³Nd/¹⁴⁴Nd ratios calculated from ID run, corrected for Sm interference and normalized to ¹⁴⁶Nd/¹⁴⁴Nd=0.7219. Two runs of the La Jolla Nd-standard during the measurement periods gave a ¹⁴³Nd/¹⁴⁴Nd ratio of 0.511857±15 (2σ_m) and 0.511847±6 (2σ_m), respectively. Error given as 2 standard deviations of the mean from the mass spectrometer run in the last digits. All analyses done at the Finnigan MAT261 mass spectrometer, except sample 36-MJV-06 and the BCR-2 standard, which were analysed at the Triton mass spectrometer.

3) Present-day and initial ε_{Nd} values (at the given age), according to Jacobsen and Wasserburg (1984); present-day chondritic ¹⁴⁷Sm/¹⁴⁴Nd ratio 0.1967, present-day chondritic ¹⁴³Nd/¹⁴⁴Nd ratio of 0.512638.

4) Model age calculated relative to the chondritic uniform reservoir (CHUR) of Jacobsen and Wasserburg (1984).

5) Model age calculated relative to the depleted mantle curve (DM) of DePaolo (1981).

TABLE IV. Zircon Lu-Hf isotope data for the Oriġġvi and Enklinge granodiorite

Sample	$^{176}\text{Hf}/^{177}\text{Hf}$	2 σ	$^{176}\text{Hf}/^{177}\text{Hf}$	2 σ	$^{176}\text{Lu}/^{177}\text{Hf}$	2 σ	$^{176}\text{Yb}/^{177}\text{Hf}$	2 σ	$^{176}\text{Hf}/^{177}\text{Hf}_i$	2 σ	ϵHf_i^1	2 σ	Age (Ga)
Oriġġvi granodiorite													
ORIGRANO-64	0.28165	0.00002	1.46735	0.00003	0.00109	0.00001	0.03624	0.00034	0.281607	0.00022	1.1	0.8	1.892
ORIGRANO-44c	0.28165	0.00002	1.46733	0.00003	0.00091	0.00002	0.03252	0.00090	0.281613	0.00023	1.3	0.8	1.892
ORIGRANO-37b	0.28161	0.00002	1.46731	0.00002	0.00106	0.00001	0.03650	0.00039	0.281569	0.00023	-0.3	0.3	1.892
ORIGRANO-48a	0.28154	0.00002	1.46728	0.00002	0.00075	0.00000	0.02504	0.00014	0.281515	0.00023	-2.2	0.8	1.892
ORIGRANO-61	0.28161	0.00002	1.46729	0.00003	0.00102	0.00001	0.03914	0.00039	0.281578	0.00023	0.0	0.8	1.892
ORIGRANO-40	0.28159	0.00003	1.46730	0.00002	0.00136	0.00001	0.04600	0.00016	0.281537	0.00028	-1.4	1.0	1.892
ORIGRANO-19	0.28163	0.00002	1.46733	0.00003	0.00152	0.00003	0.05847	0.00137	0.281580	0.00024	0.1	0.9	1.892
ORIGRANO-39	0.28167	0.00002	1.46730	0.00002	0.00119	0.00001	0.04144	0.00067	0.281627	0.00024	1.8	0.9	1.892
ORIGRANO-36c	0.28158	0.00002	1.46727	0.00003	0.00096	0.00000	0.03454	0.00019	0.281548	0.00025	-1.0	0.9	1.892
ORIGRANO-54b	0.28155	0.00002	1.46731	0.00003	0.00098	0.00001	0.03477	0.00061	0.281514	0.00025	-2.2	0.9	1.892
ORIGRANO-16	0.28154	0.00003	1.46727	0.00003	0.00107	0.00001	0.03738	0.00059	0.281497	0.00026	-2.8	0.9	1.892
ORIGRANO-21	0.28148	0.00003	1.46729	0.00002	0.00096	0.00000	0.03239	0.00013	0.281449	0.00026	-4.5	0.9	1.892
ORIGRANO-34c	0.28162	0.00003	1.46729	0.00003	0.00081	0.00000	0.02748	0.00016	0.281590	0.00026	0.5	0.9	1.892
ORIGRANO-59	0.28156	0.00003	1.46732	0.00003	0.00113	0.00002	0.04377	0.00081	0.281522	0.00026	-2.0	0.9	1.892
ORIGRANO-51	0.28154	0.00003	1.46735	0.00002	0.00075	0.00002	0.02822	0.00087	0.281517	0.00027	-2.1	1.0	1.892
ORIGRANO-34a	0.28165	0.00003	1.46729	0.00003	0.00115	0.00001	0.04046	0.00019	0.281604	0.00027	1.0	1.0	1.892
ORIGRANO-43	0.28162	0.00003	1.46727	0.00002	0.00135	0.00002	0.05065	0.00054	0.281570	0.00028	-0.2	0.5	1.892
ORIGRANO-34b	0.28157	0.00003	1.46736	0.00003	0.00074	0.00001	0.02481	0.00032	0.281545	0.00028	-1.1	1.0	1.892
ORIGRANO-37a	0.28158	0.00003	1.46730	0.00003	0.00122	0.00003	0.04348	0.00089	0.281539	0.00028	-1.4	1.0	1.892
ORIGRANO-48b	0.28161	0.00003	1.46728	0.00003	0.00194	0.00002	0.07373	0.00108	0.281544	0.00028	-1.2	1.0	1.892
ORIGRANO-32	0.28156	0.00003	1.46727	0.00003	0.00109	0.00001	0.03921	0.00039	0.281524	0.00029	-1.9	1.0	1.892
ORIGRANO-15	0.28169	0.00003	1.46733	0.00003	0.00122	0.00002	0.04194	0.00055	0.281641	0.00029	2.3	1.0	1.892
ORIGRANO-54a	0.28159	0.00003	1.46726	0.00002	0.00100	0.00002	0.03651	0.00070	0.281550	0.00030	-1.0	0.9	1.892
ORIGRANO-1	0.28163	0.00003	1.46727	0.00003	0.00146	0.00002	0.04905	0.00053	0.281574	0.00032	-0.1	0.9	1.892
ORIGRANO-36b	0.28162	0.00003	1.46734	0.00003	0.00135	0.00002	0.04544	0.00076	0.281569	0.00033	-0.3	0.6	1.892
ORIGRANO-23	0.28158	0.00004	1.46726	0.00003	0.00094	0.00000	0.03232	0.00025	0.281547	0.00038	-1.1	0.8	1.892
ORIGRANO-47b	0.28172	0.00004	1.46728	0.00003	0.00422	0.00015	0.17728	0.00629	0.281570	0.00042	-0.2	1.0	1.892
ORIGRANO-22	0.28159	0.00003	1.46731	0.00003	0.00078	0.00000	0.02692	0.00015	0.281565	0.00029	-0.4	0.2	1.892
ORIGRANO-47a	0.28157	0.00003	1.46720	0.00002	0.00216	0.00004	0.08700	0.00169	0.281495	0.00030	-2.9	1.1	1.892
ORIGRANO-29	0.28169	0.00003	1.46732	0.00004	0.00118	0.00001	0.04531	0.00067	0.281650	0.00034	2.6	1.2	1.892
ORIGRANO-45a	0.28148	0.00003	1.46734	0.00003	0.00088	0.00000	0.03121	0.00023	0.281443	0.00030	-4.7	1.1	1.892
ORIGRANO-24	0.28153	0.00003	1.46728	0.00003	0.00119	0.00003	0.04290	0.00108	0.281492	0.00033	-3.0	1.2	1.892
ORIGRANO-27	0.28170	0.00004	1.46724	0.00003	0.00200	0.00004	0.07800	0.00134	0.281632	0.00036	2.0	1.3	1.892
ORIGRANO-50	0.28152	0.00004	1.46734	0.00003	0.00160	0.00001	0.06156	0.00043	0.281466	0.00043	-3.9	1.5	1.892
ORIGRANO-63	0.28151	0.00004	1.46728	0.00003	0.00116	0.00002	0.03976	0.00116	0.281473	0.00042	-3.7	1.5	1.892
ORIGRANO-6	0.28158	0.00005	1.46734	0.00004	0.00212	0.00004	0.08390	0.00287	0.281506	0.00050	-2.5	1.8	1.892
ORIGRANO-45b	0.28148	0.00005	1.46735	0.00004	0.00090	0.00001	0.03217	0.00030	0.281452	0.00053	-4.4	1.9	1.892
Enklinge granodiorite													
Enklinge magmatic													
3-MUV-06-3	0.28164	0.00005	1.46735	0.00003	0.00280	0.00003	0.10963	0.00167	0.281543	0.00047	-1.4	1.2	1.882
3-MUV-06-18	0.28170	0.00005	1.46735	0.00003	0.00220	0.00002	0.08736	0.00043	0.281617	0.00046	1.2	1.6	1.882
3-MUV-06-29	0.28178	0.00003	1.46739	0.00003	0.00193	0.00005	0.08101	0.00226	0.281707	0.00035	4.4	1.2	1.882
3-MUV-06-46	0.28172	0.00004	1.46742	0.00003	0.00315	0.00002	0.12840	0.00176	0.281608	0.00044	0.9	1.6	1.882
3-MUV-06-94	0.28163	0.00005	1.46736	0.00004	0.00219	0.00004	0.08727	0.00142	0.281550	0.00046	-1.2	0.8	1.882

TABLE IV. (Continued)

Sample	$^{176}\text{Hf}/^{177}\text{Hf}$	2 σ	$^{176}\text{Hf}/^{177}\text{Hf}$	2 σ	$^{176}\text{Lu}/^{177}\text{Hf}$	2 σ	$^{176}\text{Yb}/^{177}\text{Hf}$	2 σ	$^{176}\text{Hf}/^{177}\text{Hf}$	2 σ	ϵHf_i^1	2 σ	Age (Ga)
3-MJV-06-210	0.28165	0.00005	1.46738	0.00003	0.00225	0.00002	0.09217	0.00112	0.281574	0.000046	-0.3	1.0	1.882
3-MJV-06-195	0.28169	0.00003	1.46732	0.00002	0.00232	0.00006	0.09049	0.00296	0.281608	0.000034	0.9	1.2	1.882
3-MJV-06-35	0.28169	0.00004	1.46738	0.00003	0.00413	0.00005	0.18094	0.00244	0.281541	0.000039	-1.5	1.4	1.882
3-MJV-06-59	0.28163	0.00008	1.46750	0.00003	0.00227	0.00004	0.08542	0.00176	0.281546	0.000079	-1.3	0.2	1.882
3-MJV-06-81	0.28157	0.00004	1.46742	0.00003	0.00207	0.00003	0.07842	0.00044	0.281499	0.000044	-3.0	1.5	1.882
3-MJV-06-152	0.28169	0.00003	1.46738	0.00002	0.00165	0.00001	0.06338	0.00045	0.281630	0.000029	1.7	1.0	1.882
<i>Enklinge inherited</i>													
3-MJV-06-65b	0.28172	0.00003	1.46740	0.00003	0.00237	0.00002	0.09022	0.00118	0.281637	0.000033	3.5	1.2	1.951
3-MJV-06-4	0.28175	0.00003	1.46736	0.00003	0.00294	0.00003	0.12776	0.00172	0.281640	0.000032	3.7	1.1	1.953
3-MJV-06-101	0.28170	0.00004	1.46731	0.00002	0.00195	0.00001	0.07306	0.00088	0.281622	0.000038	5.5	1.4	2.060
3-MJV-06-47	0.28174	0.00003	1.46739	0.00002	0.00318	0.00003	0.13976	0.00127	0.281608	0.000034	6.9	1.2	2.142
3-MJV-06-39	0.28165	0.00006	1.46736	0.00004	0.00208	0.00003	0.08172	0.00062	0.281559	0.000056	7.6	2.0	2.247
<i>Enklinge metamorphic</i>													
3-MJV-06-60a	0.28173	0.00003	1.46736	0.00002	0.00220	0.00003	0.09269	0.00139	0.281658	0.000035	0.8	1.2	1.802
3-MJV-06-60b	0.28168	0.00003	1.46733	0.00003	0.00177	0.00003	0.07396	0.00202	0.281619	0.000027	-0.4	0.2	1.810
3-MJV-06-10a	0.28159	0.00003	1.46742	0.00003	0.00250	0.00005	0.10365	0.00347	0.281501	0.000031	-4.1	1.1	1.830
3-MJV-06-121a	0.28171	0.00003	1.46735	0.00003	0.00236	0.00005	0.09578	0.00186	0.281626	0.000032	0.7	1.1	1.846
3-MJV-06-90b	0.28174	0.00003	1.46739	0.00002	0.00255	0.00002	0.10112	0.00054	0.281647	0.000032	1.6	1.1	1.856

1) Calculated according to a λ of $1.867 \cdot 10^{-11} \text{ a}^{-1}$ (Scherer et al. 2001) and the present-day chondritic values of $^{176}\text{Lu}/^{177}\text{Hf}=0.0336$ and $^{176}\text{Hf}/^{177}\text{Hf}=0.282785$ (Bouvier et al. 2008). External error based on the SD (n=26) of zircon standard GJ1 run during the analyses is estimated to be in the range of ± 1.6 to 2.2 ϵ -units.